# Analysing Cascading Hazard Impacts and Recovery at Farm Level:

## Hurunui District Farm Case Studies following the November 2016 M7.8 Hurunui-Kaikōura Earthquake

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By

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*Dry land, sudden shock*

*Cascading earth, water, stock*

*New course, same old farm*

# Abstract

Farming and urban regions are impacted by earthquake disasters in different ways, and feature a range of often different recovery requirements. In New Zealand, and elsewhere, most earthquake impact and recovery research is urban focused. This creates a research deficit that can lead to the application of well-researched urban recovery strategies in rural areas to suboptimal effect.

To begin to reduce this deficit, in-depth case studies of the earthquake impacts and recovery of three New Zealand farms severely impacted by the 14$^{th}$ November 2016, **M**7.8 Hurunui-Kaikōura earthquake were conducted. The initial earthquake, its aftershocks and coseismic hazards (*e.g.,* landslides, liquefaction, surface rupture) affected much of North Canterbury, Marlborough and the Wellington area. The three case study farms were chosen to broadly represent the main types of farming and topography in the Hurunui District in North Canterbury.

The farms were directly and indirectly impacted by earthquakes and related hazards. On-farm infrastructure (*e.g.,* woolsheds, homesteads) and essential services (*e.g.,* water, power), frequently sourced from distributed networks, were severely impacted. The earthquake occurred after two years of regional drought had already stressed farm systems and farmers to restructuring or breaking point. Cascading interlinked hazards stemming from the earthquakes and coseismic hazards continued to disrupt earthquake recovery over a year after the initial earthquake.

Semi-structured interviews with the farmers were conducted nine and fourteen months after the initial earthquake to capture the timeline of on-going impacts and recovery. Analysis of both geological hazard data and interview data resulted in the identification of key factors influencing farm level earthquake impact and recovery. These include pre-existing conditions (*e.g.,* drought); farm-specific variations in recovery timelines; and resilience strategies for farm recovery resources. The earthquake recovery process presented all three farms with opportunities to change their business plans and adapt to mitigate on-going and future risk.

# Executive Summary

The 14th November 2016 **M**7.8 Hurunui/Kaikōura earthquake damaged farms throughout the northern part of South Island New Zealand. The earthquake triggered coseismic hazards (*i.e.,* landslides, liquefaction and surface rupture) over large areas of North Canterbury and Marlborough. A series of on-going, cascading hazards stemming from the initial coseismic hazards continue to disrupt the earthquake recovery. Comparative case studies of three farms in the Hurunui District were conducted to analyse earthquake impacts and identify recovery factors at farm level. Ten key findings and their respective recommendations follow.

## 1. Pre-existing Conditions

Pre-existing conditions (*e.g.,* drought, geology) change the vulnerability of farms. Droughts can change soil properties and reduce the relative probability of slope failure. Simultaneously, farmers use a variety of strategies to reduce drought impacts (*e.g.,* selling off stock, buying supplemental feed). These strategies change the available earthquake recovery strategies and influence impact severity.

### Recommendation 1A

Adapt earthquake preparedness and recovery plans for current climate and financial situations.

### Recommendation 1B

Research the influence of climate conditions and other pre-existing conditions on farm vulnerability. Climate change will continue to make this an important influencer.

## 2. Time of Year

The time of year when an earthquake occurs can change the impacts. Seasonal variations (*e.g.*, precipitation and groundwater levels) and the farming calendar influence the coseismic hazards and subsequent impacts. For example, an earthquake during the autumn cyclones or winter rains would trigger more extensive slope failure and liquefaction than an earthquake in the middle of a dry summer. The farming calendar is also seasonally controlled; farm disruption and adaptability changes throughout the year depending on what tasks are the priority at that time.

### Recommendation 2

Farm level earthquake preparedness and recovery plans should take time of year into account. Preparedness and recovery plans for rural regions should also be aware of seasonal climatic variation.

## 3. Hazard Type And Severity Depends On Farm Type And Location

The farms chosen for the study represent two broad categories of farming present in the Hurunui District (sheep and beef; and dairy). They are located in three distinct topographic situations: low relief, river terrace; steeps hills; and hill country (elevated pastures, river valleys). The coseismic hazards varied depending on farms location. For example, liquefaction was much more prevalent on the saturated sands found adjacent to rivers and shaking was more intense in the hills due to topographic amplification. Farms with highly variable topography are more prone to cascading hazards, which increases the level of hazards over a long period of time. Farm type influences vulnerability and exposure, which changes hazard severity.

- Hazard type depends on the geologic/geographic properties of the farm
- Hazard severity is influenced by farm type and farm management decisions

Recommendation 3

An increase in the pool of farm level earthquake impact studies in New Zealand is required to expand understanding of the influence farm location and type have on earthquake risk. Further investigation of the long-term impact of cascading hazards at the farm level is also advised.

## 4. Cascading Hazards

Cascading hazards are more common in areas of more variable topography. This does not mean they are exclusively limited to these areas. Changes to rivers in low relief areas can also lead to additional flooding or changed flood patterns. On-going hazards such as drainage change flooding and landsliding can impact most farms.

Recommendation 4

Farmers and organisations operating in rural environments should consider the concept of cascading hazards in their post-disaster recovery plans. Future land-use plans should also take into account potential cascading hazards.

## 5. On-farm Asset Resilience

Farms are reliant on long, exposed distributed infrastructure networks (e.g. electricity and road) or they must supply their own essential services in part, if not completely. This means that in a disaster where there has been disruption of these essential services, farmers either need to have the capacity to repair those systems, have access to redundant/alternative systems, or be supported by a timely and effective restoration of those services.

### Recommendation 5

Farmers should procure back-up systems for their essential services. For example, this can be redundant water system elements, power generators, or ready-access to excavators for track repair.

## 6. Farm Level Recovery Timeline

Farm earthquake recovery takes place in three major stages: initial response, short-term recovery and long-term re-planning. The length of each of these stages varies between farms and the transitions between each stage are gradual. After the initial stage (emergency recovery of life and lifelines), individual farm priorities in terms of repairs, rebuilds and restoration of functionality take over.

### Recommendation 6

Rural recovery plans, at all levels, should take variable farm recovery rates and timelines into account. The length of each stage is broadly predictable and regional or local aid can be timed to assist farms depending on what recovery stage they are currently in. Outside organisations should also recognise that farms moving into the long-term re-planning stage does not mean that all repairs are complete or will be complete for several years. Aid such as fence repair support can be beneficial with in the first few years due to on-going hazard damage and the often widespread extend of initial damage.

## 7. Farm Type Influences Recovery Timeline

There were several key differences in the greatest impact and recovery timing between the dairy farm and the two sheep and beef farms in this study. The dairy farm was initially more heavily impacted because of the coseismic damage to a high use dairy shed. The strong off-farm network inherent in dairy farming made for rapid assistance and repair on a large scale. The sheep and beef farms had a greater degree of on-going hazards and thus a more protracted recovery period. Many resources were internally or much more locally sourced.

- Vulnerability, resources and recovery timelines differ between farm types
- Farm type priorities (*i.e.* high dependency on the dairy shed versus a woolshed) influence earthquake vulnerability

### Recommendation 7

Further studies using a larger variety of farm types will help guide preparation, aid and recovery plans that may be tailored for individual farms.

## 8. Mental Health

The cascading effects of disasters effect every aspect of farm life. Stress is cumulative and diminishes energy and recovery speed. The loss of emergency assistance, when it is still required to some degree, can cause further trauma. This is inevitable and must be planned for. National and regional media and public attention fades away as the initial response stage comes to an end. This is long before recovery is complete. The isolation this sudden loss of attention and aid causes can exacerbate mental stress.

Recommendation 8

Recognise, research and expand mental health resources for rural areas. Address the stress created by the removal of emergency aid and assistance. Combat the isolation feelings and reality this retraction from the area creates.

## 9. Insurance

In mid-December 2016, the Earthquake Commission (EQC) closed a deal with private insurers to manage processing for earthquake claims covered by EQC. The goal of this agreement was to simply speed the insurance process for claimants. Two of the three farms expressed recovery difficulties stemming from insurance processing. The effectiveness of this new arrangement requires further assessment. Regardless, the insurance process is complex, long and helps drive recovery rates.

Recommendation 9A

Farmers should hire a lawyer to review their insurance policies pre-earthquake. Post-earthquake, a lawyer should be involved early in the insurance claims process.

Recommendation 9B

Post-earthquake, insurance companies operating in the rural sector should debrief their clients. This was the first earthquake in which private companies handled EQC claim settlements. There are a number of lessons to be learned from this process.

## 10. Future Earthquake Risk Adaption

The final stage of farm earthquake recovery is re-planning. Farms adjust to their changed assets and new hazard awareness. Strategies are a mix of conservatism and optimistic diversification and expansion, depending on the experiences of the farm.

Recommendation 10

There is a present need for the research and development of resources for earthquake resilient farms focusing on land-use and business plan changes, as well as preparedness strategies.

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# Chapter 1 Introduction

## 1.1 Thesis Context

Rolling, sheep-covered hills is a common popular image of New Zealand. Farms are a large part of Kiwi heritage and culture and are major tourism draw. They are also a major contributor to New Zealand's economy. Dairy products alone are New Zealand's largest export at $1.9 billion in late 2016 (Statistics New Zealand 2018). In 2012, there were over 58,000 farms (Statistics New Zealand 2013a). Most were primarily livestock, and were either dairy cattle or sheep and beef. When natural disasters impact farms, they damage the national economy by reducing production rates.

Earthquake and coseismic hazards can cause significant immediate and on-going damage to farms. Coseismic hazards include strong ground shaking, landslides, landslide dams, surface rupture, liquefaction and rockfall. These can directly and indirectly damage farm infrastructure (*e.g.,* dairy shed, woolshed, homestead) and essential services (*e.g.,* water, power, telecommunications, transportation), and threaten the lives of humans and livestock. The 4$^{th}$ September 2010 **M**7.1 Darfield earthquake was the last significant rural earthquake in New Zealand. The farms on the Canterbury plains suffered both structural and non-structural damage (Whitman *et al.* 2013). The earthquake impacts on farms differ from those experienced in urban areas. This is because farms have different vulnerability factors and do not have the same networks and resources as urban areas.

At time of writing there are few farm-level earthquake impact studies in New Zealand and globally. So far most farm hazard impact studies have focused on climate or volcano-related hazards rather than earthquakes (Whitman *et al.* 2013). As a consequence, the most researched earthquake impact and recovery studies and plans focus on urban areas. Urban recovery needs differ from rural recovery needs, so applying even the best researched urban earthquake recovery plans can contribute to sub-optimal recovery in rural areas. Further research is required to identify farm-level specific recovery factors and develop farm-focused earthquake recovery plans.

Farm vulnerability is dependent on a number of factors, including pre-exiting conditions (Craig *et al.* 2016a). Farmer strategies for surviving on-going stressors, such as droughts, influence their vulnerability and the feasibility of various recovery options.

Environmental conditions may change hazard severity either through long-term climate change or seasonal variations. Disaster impacts can be cascading, on-going and continue to impact farms for years after the initial event (Craig *et al.* 2016b). Landslides can be reactivated by rainstorms days to years after an earthquake weakens the soil. Ground deformation can change drainage patterns. Over time this can trigger landsliding and flooding, which can be of particular note in areas where it was not prone to either pre-earthquake.

Farm type also factors into farm vulnerability (Whitman *et al.* 2013). Farms in general have different vulnerabilities and resiliency attributes than urban business and residential areas (Farmar-Bowers & Lane 2009). Farm resilience is rooted in farms being both places of residence and businesses, particularly with family farms (Darnhofer 2010). Studies in urban environments are more prevalent. In particular, there are far more urban business-focused studies than rural business–focused, or even more specifically farm-focused, studies. In addition, the recent New Zealand experience of large earthquakes is predominantly urban based. Therefore, urban recovery strategies are more researched and practiced than rural ones. Rural earthquake impact studies at every level are required to improve and develop rural-specific earthquake recovery plans. As the best way to improve recovery is to decrease impact, farm level preparedness strategies must also be developed.

In recent years, the New Zealand public has become more aware of earthquakes and their impacts. New Zealand is an earthquake prone country; there have been at least 21 on or near-shore shallow ≥**M**6.5 earthquake in New Zealand since 1840 (Nicol *et al.* 2016). The coseismic hazards vary between localities. Mountainous regions are more prone to earthquake-triggered landsliding and rockfall and display topographically-amplified ground shaking. In areas that are low relief with saturated, sandy soils, liquefaction is the main coseismic hazard. Surface ruptures are localised, but regionally-extensive features. Each of these hazards can damage farm infrastructure and essential services. The farm level recovery timelines from this damage is not well detailed. Given increased public awareness of these hazards, it is an opportune time to improve community specific resilience.

The occurrence of the 14$^{th}$ November 2016 Hurunui/Kaikōura earthquake, a high magnitude (**M**7.8) earthquake, in a rural area presented the opportunity to develop in-depth farm-level case studies. The development of the case studies and recording of the timeline concurrently with the recovery period allowed for capturing minute details that might have faded from memory over time. This thesis presents and analyses the earthquake impacts and recovery of three Hurunui District farms to aid the development of recommendations to improve farm earthquake resilience.

## 1.2 Project Background

At 0:02 NZST on November 14th, 2016, a **M**7.8 earthquake initiated near Waiau in the Hurunui District of the South Island, New Zealand (Geonet 2016). The earthquake rupture propagated north and east across the Hurunui District, continued up to Marlborough and terminated offshore in the Cook Strait (Figure 1). Farms and towns throughout North Canterbury were damaged by the shaking, co-seismic hazards and cascading hazards. The natural hazard cascades damaged, disrupted and destroyed on-farm farm infrastructure (*e.g.*, irrigation systems, shearing sheds) and essential services (*e.g.*, roads, electrical power) throughout the Hurunui District. As a result of these cascades, the region's farms have experienced on-going economic impact, long after the initial shaking stopped (Stevenson *et al.* 2017).

Cascading hazards are a series of hazard events that linked through various triggering mechanisms. They can occur over short (seconds) and long (years) periods of time. Cascading hazards have often mistakenly been included under multi-hazards in previous literature and policy. This interpretation over-simplifies the complexity of the interdependent networks involved. The concept currently lacks a standardised definition, data collection approach and impact assessment methodology.

Many lessons from the 2010-2011 Canterbury Earthquake Sequence (CES) were applied to the 2016 North Canterbury Earthquake. As most areas impacted during the CES were urban or near-urban areas, this approach has highlighted a lack of understanding of the needs of agricultural communities during earthquake impact recovery. For example, the red zoning technique for identifying properties in areas deemed too dangerous to live, cannot be applied in rural areas the same way as in urban areas. This is because the land blocks are much larger, and usually only smaller areas within a farm block require red zoning. Also, in rural agricultural areas the land owner's land is both their home and place of work, so the economic weight of the land block is much greater.

This thesis presents in-depth case studies of the impact to and recovery from the earthquakes on three farms in the Hurunui District. It relies on data collected through semi-structured interviews and timeline exercises conducted with farmers from three farms in the Hurunui District. These interviews and exercise took place in two rounds. The first round approximately nine months after the earthquake (August 2017) and the second round approximately fourteen months after (January 2018) after the event. This spacing was a deliberate attempt to capture the temporal components of cascading hazards and impact recovery. These interviews are supplemented by regional and on-farm natural hazard mapping.

## 1.3 Research Objectives

### 1.3.1 Overarching goal

The main goal of this thesis is to present three in-depth case studies covering cascading hazard impact on farm infrastructure following the 2016 Hurunui/Kaikōura earthquake. The case studies present a holistic look at initial and continuing post-event impact and future land-use planning.

### 1.3.2 Research Objectives

- Investigate the impacts on farm infrastructure and essential services from the November 2016 earthquake and its related hazards
- Identify key factors that influence farm earthquake risk
- Develop farm level earthquake recovery timeline
- Analyse the spatial and temporal components of cascading natural hazards
- Place farm-scale cascading hazard impact into the framework of impacts to the rural, agriculture community
- Develop recommendations for farmers and non-farmers operating in the agricultural sector to improve earthquake resilience

## 1.4 Scope

The scope of this thesis is the impact and recovery at the farm-level of three Hurunui District farms from the 14th November 2016 earthquake. This includes the state of three farms immediately pre-earthquake, farm assets (*e.g.*, homesteads, water pipes, livestock) and human resources (*e.g.*, farmers, staff), farm economic plans, the initial earthquake impacts, earthquake related-hazards and the recovery stages over the fourteen months following the earthquake. The contribution of off-farm groups (*e.g.,* government agencies, insurers) to the recovery efforts of these farms was also explored. The wider community and regional recovery was only included to demonstrate extent, timing and as a comparison to the three case study farms.

## 1.5 Research Methodology

1. **Ethics**

   A low risk application was approved by the University of Canterbury Human Ethics Committee on 31st July 2017 (Appendix C).

2. **Document Analysis**

   Research began by drawing from peer-reviewed literature covering cascading hazard research, farm infrastructure hazard impact models and 14th November 2016 earthquake impact studies. It also drew on grey literature, media and government reports. Geohazard data produced by the University of Canterbury was used to develop a farm-level and regional understanding of the post-earthquake hazard scape.

3. **Interviews**

   Three Hurunui District farmers (On-farm farm owners) were invited to participate in two rounds of semi-structured interviews in August 2017 and January 2018. These farms were purposive sample of the Hurunui Distract farming community and represent the farming type and topographies present in the district (extensive hill country sheep and beef; steep hill sheep and beef; low relief dairy). Participation was voluntary and confidential. The interviews were digitally recorded and transcribed.

   The confidentiality of the participants was maintained. During the project, the confidential records were maintained a password protected folder on a desktop computer and a portable hard drive in a locked cabinet on campus. Following project completion, the confidential records (digital and written) were handed over to a supervisor to be kept securely for a period of 5 years after which point they are to be destroyed.

4. **Data Analysis**

The transcript data was divided into text segments, summarised, assigned themes and sorted into broad categories using a general inductive approach (Thomas 2016). The findings and recommendations presented within this thesis were developed from this analysis.

## 1.6 Literature Review

### 1.6.1 Cascading Hazards

Cascading hazards are a sequence of interlinked events often analogised as "toppling dominos" (Pescaroli & Alexander 2016). 'Cascading hazards' has neither a universal definition nor is there a standardised approach to dealing with them. This lack of understanding magnifies the risk they pose to critical infrastructure and essential services. Current policies and most other studies mistakenly include the concept under multi-hazards, giving the impression of a single initial trigger and linear cascade sequence. UNISDR (2009) includes cascading hazards under its definition of multi-hazards, which over-simplifies the complexity of the interdependent networks involved. Cascading hazards are inadequately dealt with in impact assessments and land-use plans.

Some researchers reject the linear event sequence because critical infrastructure intersections are too complex. Pescaroli & Alexander (2016) propose a methodology focused on critical infrastructure vulnerability rather than deterministic worst-case scenarios. The key to this methodology is identifying the susceptible nodes that could trigger secondary events. Pescaroli & Alexander (2016) state that the next step in risk assessments is to create "worst-case amplification scenarios" instead of the traditional initial trigger-based scenarios.

Cascading effects are a chain of impacts that change vulnerability over space and time (Gianluca & David 2015). A collection of cascading effects that progress over time and stem from the same extreme event are referred to as a cascading disaster.

Kumasaki *et al.* (2015) categorised cascading hazard linkages into four types or modes:

- Striking: a primary event triggers secondary event through energy transfer,

- Undermining: a primary event reduces system stability triggering secondary event,
- Compounding: a primary event leads to increased mass or system change that triggers secondary event, and
- Blocking: a primary event blocks normal flow patterns, which leads to secondary event in the form of pressure build up.

These linkages can be seen in other studies; landslides block rivers creating lakes, which leads to further flooding downstream following blockage breach (Nguyen *et al.* 2012). The time between the primary and secondary events is a key factor, especially when the secondary event is a delayed effect.

Most cascading hazard disasters focus on the impacts to industry and urban infrastructure rather than natural hazards (Kumasaki *et al.* 2015). Xie *et al.* (2013) conducted a study that focused on modelling cascading effects in a transportation system following a snowstorm by using a computer general equilibrium model (CGE). It is suggested that the CGE could be applied to natural hazard systems, but natural hazards linkages are harder to quantify than industrial cascading disasters. Nguyen *et al.* (2012) examine rainfall-triggered landslides and the impact of secondary hazards on urban infrastructure on Madeira Island. The hilly topography of Madeira Island is more similar to that encountered in the Hurunui District, than most of the rural and earthquake case studies presented in this literature review. The study notes the pre-existing condition of wet ground lead to rapid over-saturation and debris flows. Similar to compounding, pre-existing conditions increase the destructiveness of the landslides. In a positive effect of pre-existing conditions, good climate leading to good supplementary feed stores can mitigate disaster impacts on livestock (Wilson *et al.* 2009).

#### *1.6.1.1 Temporal Factors*

Time is a major factor in determining the impact of cascading hazards, both with relation to time of year and the length of time between linked hazards. Land-use planning relies on adequately predicting the changes over time that the environment and community will undergo. These plans are for both short term decisions, immediately after a major event (*e.g.*, an earthquake), and longer-term decisions (*e.g*., permanent crop and livestock choices).

Seasonal changes to the environment play a role in the recovery process because of the time-variable farming schedule. The 2010 Darfield earthquake occurred in Spring, which aided in the recovery process (Almond *et al.* 2010). The ground, cracked by lateral spreading and surface rupture, was wet enough to roll and flatten easily. Also, the water requirements at the time of the Darfield earthquake were lower because irrigation was not necessary (Whitman *et al.* 2013). The late autumn/ winter-eruptions of three volcanoes in Patagonia (1991, 2008-2011, 2011-2012) was thought to have caused more damage due to low seasonal vegetation growth and consequently diminished soil protection (Craig *et al.* 2016b). Livestock birthing seasons and significant crop growth times are the most vulnerability times of years for farms (Whitman *et al.* 2013).

Sometimes, the effects of the secondary hazards are delayed. For many months and years after the Patagonian volcanic eruptions, the tephra was remobilised by aeolian and fluvial processes, after the initial eruption had ended and expanded the exposure area (Craig et al. 2016b). The impacts on livestock and vegetation are the same regardless of deposition mode, eruption or remobilisation. The researchers found instances where the tephra was still impacting farms sixteen years later. The complex factors, including climate, topography and land use, that influence tephra remobilisation make its potential future impacts difficult to estimate. Long-term effects also include lost production time; in orchards, it takes years for trees to regrow and mature after a storm event (Mohan & Strobl 2016).

#### *1.6.1.2 Previous Studies on Multi-hazards*

Cascading hazards have been typically included under the umbrella of multi-hazards in previous studies. Examining previous multi-hazards is the best way to investigate other cascading hazard incidences and the assessment methodologies that handle them. (Robinson *et al.* 2015) created a model for the economic multi-hazard impacts of an Alpine Fault rupture across multiple critical interdependent South Island infrastructure networks called MERIT (Modelling the Economic Resilience of Infrastructure Tool). MERIT was built using the information from several single hazard event scenarios. The model focuses on the resilience level of interlinked networks through expert knowledge of repair times. A breakdown of an electricity, transportation, wastewater or irrigation water network can cause serious disruption in the other networks. The interaction between the electricity system and the water and wastewater systems were not covered in fine detail due to high local variability and data unavailability. The modeller relied heavily on expert knowledge (elicitation) because previous studies have shown to provide a high level of realism. For example, on the West Coast many medical personal live in Hokitika, but work in the Greymouth hospital, which increases the value of transport connection between the two communities. The modellers suggested possible pre- and post-event mitigation and adaptions.

Robinson *et al.* (2016) estimate the landsliding and landsliding impacts related to a possible Alpine Fault earthquake. The study is an initial-event trigger hazard assessment that uses an Alpine Fault rupture. The study is on a regional scale, so applying it at a local, farm level will require scaling. Their model suggests landsliding is responsible for the equivalent of several years of river erosion, which suggest in terms of hazard impacts landslides rank high above annual river erosion rates. In other areas rainfall and uplift are more influential, so regional geomorphology is a key factor.

Kongar *et al.* (2015) conducted an impact assessment of infrastructure after the 2009 L'Aquila and 2011 Christchurch earthquakes. Their method lays out exactly what assets are being referred to, the physical impact and the functional impact. They point out that some logistical interdependencies, such as radio communication, road networks and gas networks, are only apparent when problems arise during emergencies. The electrical system was responsible for many operational interdependent failures (*e.g.*, waste water system plant shutdown).

Pre-existing conditions such as climate states stress systems pre-event and can influence event impact severity. The steppe farms suffered a greater impact after the Cordón Caulle eruption due to the on-going drought (Craig *et al.* 2016a). The conditions were already difficult before the eruption because the farmers were having to buy extra feed for the animals. They were not prepared for compounding hazard effects.

### 1.6.2 Resilience and Sustainable Recovery

Sustainable recovery is of prime importance if farmers are to remain living and working where they are now. Successful farmers incorporate cultivation diversification, flexibility and a system of strategic pivot points in the annual plan (Burton & Peoples 2008).

Sustainable means an action or practice that is adequate with current operating needs and does not negatively impact future operating needs (Saunders & Becker 2015). Resilience is both a short-term 'bounce back' from disaster ability and an adaptive ability. Adaptive capacity means ability to change to handle the negative impacts of an event while currently experiencing those effects. Adapting and 'bouncing back' are not the same thing; adapting implies the new stable stage achieved is slightly different than the pre-event condition. Sustainable development addresses economic, environmental and social well-being needs and sustainable recovery addresses new risk recognition and risk reduction. Recovery can be both resilient and sustainable when the changes made to return to a stable stage have a long lasting positive effect on a community's ability to react to disasters in the future. For example, the resilient liquefaction clean-up reaction to the Darfield earthquake was not sustainable because they did nothing to reduce future effects (Saunders & Becker 2015). Similarly, insurance policies that replace 'like for like' are not sustainable policies. The red zoning, retiring, of some land after the 2011 Christchurch earthquake may be more a sustainable practice in the long run (Saunders & Becker 2015).

After the 2010 Darfield earthquakes, it took several days for a coalition called Rural Recovery Group to form based on pre-existing relationships and structure (Almond *et al.* 2010). Researchers had to develop the expertise in remediating the effects of surface rupture and liquefaction on farmland post-earthquake. There was no knowledge base or action plan in place before the event, so recovery was most likely prolonged.

Interdependent networks can limit resilience. The reliance of the telecommunications and railway systems on the electrical network increases vulnerability (Yu *et al.* 2010). Yu *et al.* (2010) suggest redundancies in the telecommunications network would reduce the network's vulnerability to landsliding and liquefaction. They also noted that pre-event resource allocation (*e.g.*, bridge replacement centres) and total resource availability impacted lifeline restoration times.

Craig *et al.* (2016a, 2016b) report several resilient recovery steps taken by the residents of Patagonia in response to volcanic eruptions. Many farmers used greenhouses and shelter belts as a resilient adaptive measure against the on-going effects of ash remobilisation (Craig *et al.* 2016b). Dry climates and pastoral farmers had less irrigation and cultivation equipment and thus were less adaptable. Other farmers were forced to resort to farm abandonment because of the ongoing effects of ash remobilisation. Also, the electricity network was upgraded to resist ash abrasion and a new well was dug to handle the increased water demand in response to ash remobilisation clean-up. Some systems were resilient and sustainable; one town, Jacobacci, had a water system that was resistant to ash because it was enclosed. The ashfall did increase the needed frequency for system maintenance in the water systems of all the towns studied due to abrasion or increased water demand. A group's risk tolerance is a resilience factor. The roads stayed open under 50mm of ashfall in Patagonia, while the roads in New Zealand closed under less than 3mm (Craig *et al.* 2016b).

Folke *et al.* (2003) identify four factors that, across temporal and spatial scales, create a system's resilience. They are: "learning to live with change and uncertainty; nurturing diversity for reorganization and renewal; combining different types of knowledge for learning; and creating opportunity for self-organization toward social-ecological sustainability".

Berkes (2007) expands on these four factors. Living with uncertainty is present at an individual and societal level. Society's memory of disasters is longer and so, society tends to rebound better from a disaster than an individual. Diversity applies to all aspects of a vulnerable system (*e.g.*, crop type, products, job types, services). Diversification also applies to knowledge sources as well. Local knowledge, as with case studies, helps fill in the detail gaps of global science. Berkes (2007) also explains how the weak local response capacity can occur even in affluent areas (*e.g.*, American Samoa responded worse to a hurricane than Tikopia did to a tsunami). Local governments can and should be linked to upper levels of government, but they should not be entirely reliant on them (*e.g.*, Inuit hunter-trappers and the Artic Council tackling climate change). A system has the advantage of being composed of multiple people and benefits from the memories of multiple people and predecessors. This collective memory decreases deaths in events with long recurrence cycles. One of the most notable examples of this was during the 2004 Boxing Day Tsunami. The large number of survivors on the heavily impacted islands in the Andaman Sea was reportedly due to their oral traditions, which taught them to escape to high ground when the sea retreated (Gunawardene & Noronha 2007). The system needs to be self-organised to react adaptively; inflexibility makes dealing with uncertainty worse. Policies of decision-making centralisation decrease resilience because they reduce the chances local organisations can learn and develop their own knowledge and links.

#### *1.6.2.1 Agricultural Resilience Strategies*

Farmers have a number of resilience strategies that they rely on during disaster recovery and long-term hardship. Approximately, half of surveyed farmers reported that they turned to a bank or meat company for financial assistance during a hard period (Parsonson-Ensor & Saunders 2011). This option was far more popular than off-farm spouse work (11%), sale of land (8%), off-farm work by the farm (8%) and other options. The strategies New Zealand farmers take changed slightly from 1986 to 2010. The number of dairy cows and farms has grown exponentially, while sheep farms have shrunk over the same time period. Parsonson-Ensor & Saunders (2011) infer this is the reason for the increase in willingness to buy land and irrigate more because there is an increased need for dairy cow feed. Environmental conditions, such as drought, drives the stock increase or reduction trend.

Farmar-Bowers & Lane (2009) examine farmer decision-systems to suggest biodiversity policy approaches. They attribute actions to a combination of personal components (*e.g.*, knowledge, land, capital, interest), external component (*e.g.*, market, insurance, government programs) and random components (*e.g.*, price fluctuations, droughts, disasters). They also noted that farmers actively create opportunities that are suitable (fit motivation) and available (resources accessible). Land-use changes are due to family decision-system, farm business trading decision-system or land-ownership decision-system. A farming family's position along the life-cycle of the farm also influenced their decisions. Farmar-Bowers & Lane (2009) develop the concept of 'lens' to explain the influencers on farmer decisions (e.g. intrinsic interest, family, knowledge of personal strengths, society and knowledge of outside influences). They suggest that government policies should seek to play through these lenses to be effective. For example, education (at any level) can influence both intrinsic interest and knowledge of personal strengths.

#### *1.6.2.2 Agricultural Community Resilience Strategies*

Darnhofer (2010) conducted a case study of Austrian family farms to assess if the four resilience factors identified by Folke *et al.* (2003) and Berkes (2007) apply to farming resilience. Family farm economic strategies do not conform with mainstream economic strategies (Farmar-Bowers & Lane 2009). The goal of farm resilience is to maintain the function of the farm, not necessarily the specific production activities (Darnhofer 2010). That means farmers react to economics to preserve the farm (e.g. converting from mostly sheep to dairy farming). The farms in Darnhofer (2010)'s study were all small, approximately 17ha, so the findings may not be perfectly applied to the larger New Zealand farms discussed in this case study. Farmers often have a personal connection to land, a sense of 'belonging' (Delind & Bingen 2007). This belonging fuels a desire to stay on the farm and builds community loyalty. This desire can also stretch past a person's lifetime (*e.g.*, planting trees to grow a forest). Shocks, unexpected, short-term devastating events (e.g. earthquakes), and stresses, long-term changes (e.g. environmental policy regulation shift) both test farmer resilience (Darnhofer 2010). Farmers learn to adapt to change, diversify (crops, livestock, economic opportunities, resources, relationship types), call on different sources of knowledge (science research, traditional methods, neighbours) and community engagement. Some forms of uncertainty were considered more acceptable than other. For example, the small Austrian farmers considered 15-20 year credit plans with banks too long, but were willing to make large monetary and time commitments as part of a consortium with other farmers. Community engagement plays a part in all resilience factors. It is a source of knowledge, collective financial aid and social support through hard times.

### 1.6.3 Land-use Planning

Land-use planning is part of an effective vulnerability modification plan, but it is often bypassed for more reactionary forms of recovery post-event (Sapountzaki *et al.* 2011). Poor land-use or spatial planning, can lead to maintaining or even increasing the risk level.

Few Civil Defence & Emergency Management (CDEM) plans use pre-event planning for reduction and recovery, thus missing out on potentially less costly options (Becker *et al.* 2008). To address this deficit, Becker *et al.* (2008) developed a framework for pre-recovery land use planning that emphasises communication between various expert groups (insurers, risk managers, land owners, construction industry personal, *etc.*). Bathrellos *et al.* (2012) use pre-event land use planning on a large scale by incorporating natural hazard maps in their rural rejuvenation land use planning methodology for Trikala, Greece. They attempt to show an alternative to the traditional socio-economic factors method. Their methodology includes expert opinion weighted physical factors (natural hazards, geology and geomorphology) and socio-economic factors. The hazard maps they use are single hazard only (erosion, landslide, flood, earthquake), which for a high-level regional analysis may be all that is required. Robinson *et al.* (2015) briefly touch on pre-event land-use planning during their risk adaption sections where they discuss the benefits of relocating the community of Franz Josef.

### 1.6.4 Previous Rural and Agriculture Hazard Studies

There are three types of farms: arable (crops only), mixed (crops and animals) and pastoral (dairy, sheep, *etc.*). A farm's main source of profit (crops or livestock) is also their biggest vulnerability (Lawes & Kingwell 2012). Vulnerability severity is farm-type specific. Pastoral farms (especially dairy) are most vulnerable to electricity outages, arable farms to water system break-downs and ground-deformation and mixed to livestock health (influenced by water and feed access) (Whitman *et al.* 2013).

Most hazard impacts on farm infrastructure studies focus on single event impacts. Craig *et al.* (2016a, 2016b) conducted a post-event impact assessment of tephra falls on agricultural areas in Patagonia, South America, following three volcanic eruptions. They use a combination of site visits, tephra thickness isopach maps from previous studies and semi-structured interviews with farmers, production managers and agricultural agency staff to collect data. This study converts qualitative to quantitative data to improve comparison accuracy and account for variable regional settings. The farm type, pastoral or horticultural, also changed the severity, timing and mitigation strategy. The study uses maximum loss to estimate recovery. The climate and farm type were the best predicative factors for estimating tephra remobilisation impact (Craig *et al.* 2016a).

Most risk assessment studies for agriculture focus on climate related hazards (Burton & Peoples 2008; Dong *et al.* 2016; Mohan & Strobl 2016). Both Dong *et al.* (2016) and Mohan & Strobl (2016) focus on risk impact as a function of economic loss and calculate future loss as a result of a given hazard's impact. Burton & Peoples (2008) take a different approach using semi-structured interviews and qualitative data to examine adaptive strategies for farmers in droughts. Dong *et al.* (2016) use crop yield as a direct impact expression for on-going climate events (drought, floods, heat waves, climate-induced soil erosion). Mohan & Strobl (2016) calculate the future impact of hurricanes on the agriculture of various Caribbean islands. Mohan & Strobl (2016) attempt to correct for the limited hurricane data by introducing synthetically calculated events. They used a statistically deterministic method and pre-exiting meteorological and storm models. Their use of this data and method means that the results are relevant for the near future only and means the method may not be adaptable to other regions.

#### 1.6.5 Historical Rural Earthquake Impact Cases

Whitman *et al.* (2013) notes that as of 2013 there were no international studies on the impact of earthquakes on agricultural organizations. The research for this literature review have revealed few studies in the intervening years. Agriculture damage is frequently treated as a side note. The following are three key New Zealand rural earthquake studies. See Appendix A for a longer collection of similar global studies.

On May 25th, 1968, a **M** 7.1 earthquake occurred near Inangahua Junction, South Island, New Zealand (Earthquake Commission 2015). It took nearly seven hours for rescue helicopters and damage surveyors to arrive because the town was almost completely cut off and damage elsewhere was minor.

On March 2nd, 1987, a **M** 6.3 earthquake occurred near the Eastern Bay of Plenty, North Island, New Zealand (Butcher *et al.* 1998). Shaking, ground deformation, liquefaction and slope failures were the predominate forms of damage. Kiwifruit orchards, which were just about to be harvested, suffered collapsed support structures and the packing sheds were shaken, but the damage was not severe enough to prevent the harvest from commencing on schedule. Ground deformation changed the natural drainage systems, damaged boreholes for irrigation water and created new springs. The loss of electricity and water systems as well as stress were the highest reported problems. Similar issues were reported for the 2010 Darfield earthquake. A Rural Support Group, Civil Defence and local Whakatane Branch of Federated Farmers checked-in on farmers, surveyed for necessary assistance, provided assistance and repairs. There was a reported NZ$20 million of damage to 600 properties.

On September 4th, 2010, a **M** 7.1 earthquake occurred on a previously unidentified fault near Darfield, Canterbury, New Zealand (Almond *et al.* 2010). The land closest to the fault surface rupture was mostly arable and pastoral (dairy) farming. Most farms near the fault experienced ground shaking, liquefaction (lateral spreading, sand ejection and 'sand blisters'), surface rupture related damage and animal injuries (dairy cows reportedly broke legs while standing on concrete milking shed floors). Loss of electricity was reportedly the most disruptive impact to dairy farms (dairy sheds), while water system damage (pipes and wells) was the greatest impact for mixed or arable farms (Whitman *et al.* 2012). Several dairy farms used generators as temporary mitigation. Despite the physical damage, the psychosocial traumas associated with the event were more concerning to the farmers questioned. The strongest mitigating factor for many farmers was their relationship with their neighbours; a trait generally not shared with urban organisations.

## 1.7 Case Study Area

### 1.7.1 Regional Geology and Geomorphology

The Hurunui District is located in North Canterbury, South Island, New Zealand (Figure 1). The region sits astride the main Australia-Pacific Plate boundary marked by the Alpine Fault and related fault systems. The area is mostly hills and river valleys bounded by the northernmost section of the Southern Alps, and the Inland and Seaward Kaikōura ranges.

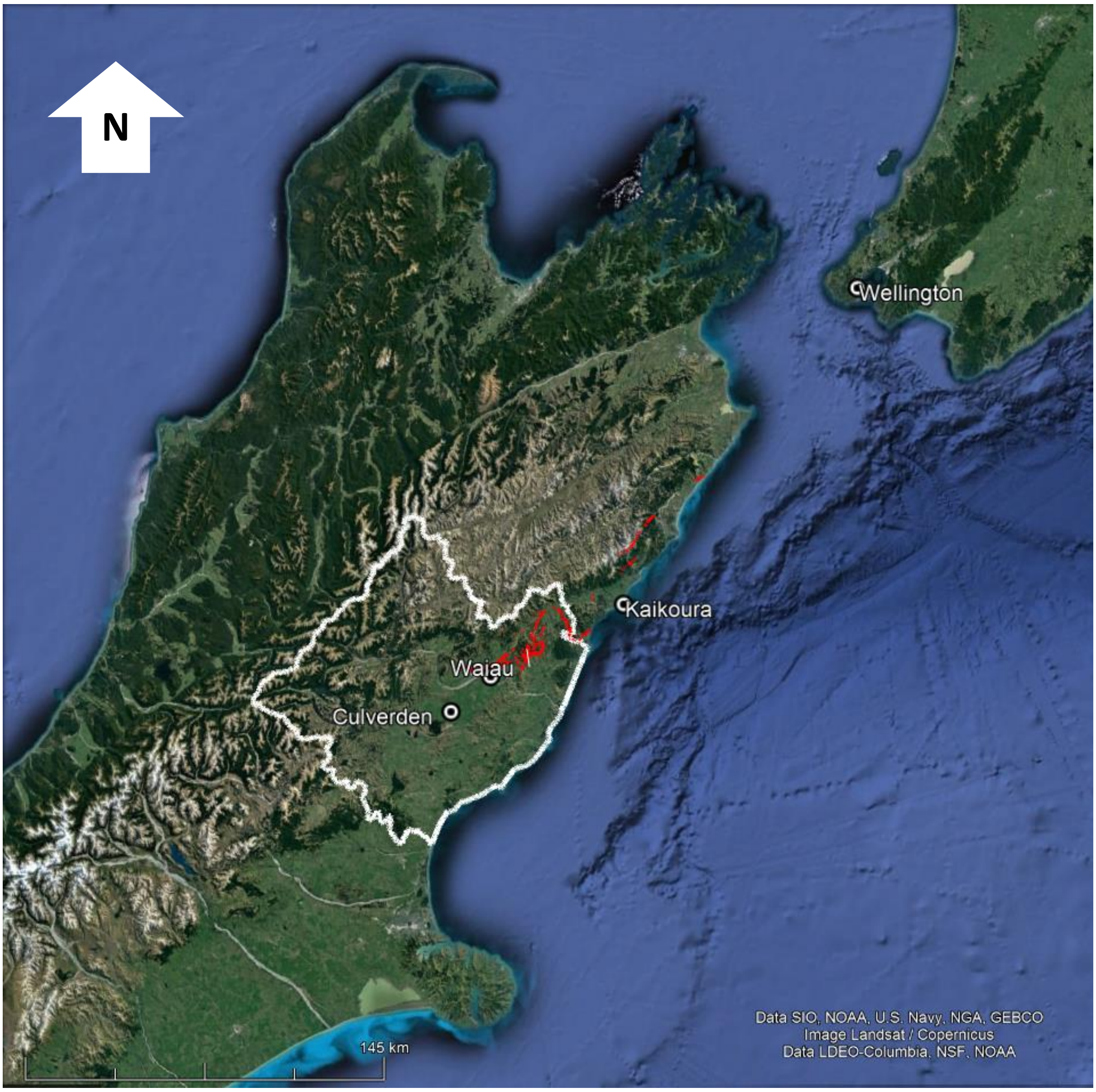



*Figure 1 Regional map. Hurunui District outlined in white sourced from (Statistics New Zealand 2011). 14th November 2016 surface ruptures marked in red (Litchfield et al. 2018; Nicol et al. 2018).*

### *1.7.1.1 Geological History*

The North Canterbury region has had a complex geological history including periods of marine transgression, tectonic uplift and erosion (Rattenbury *et al.* 2006). Most of the rocks occurring below the Quaternary sediments are 'basement' Torlesse Group and erosion-resistant igneous intrusions. There are smaller outcrops of weak marine sedimentary rocks. Glaciation in the Quaternary led to the formation of many lakes (*e.g.*, Rotoiti, Rotorua, Sumner). Large rivers run from these lakes cutting gorges and valleys.

During the Quaternary, the Southern Alps and mountain ranges throughout Marlbourgh, Nelson and northern Canterbury uplifted and the region was subject to widespread erosion. Alternating glacial and interglacial climatic fluctuations then gave rise to the sediment deposits (soils) that occur across the region.

#### *1.7.1.2 Tectonic History*

North Canterbury has a long tectonic history record extending back to the early Ordovician (Rattenbury *et al.* 2006). It is still tectonically active today. Located on the Australian-Pacific plate boundary the region is crossed by a number of major active faults, several of which have generated damaging earthquakes in historical time.

#### *1.7.1.3 Geological Units*

Basement Torlesse greywacke, formed from the Cambrian to early Cretaceous, is generally more resistant to erosion than the younger overlying sedimentary rocks. In places where the rock has been heavily fractured by faults or through folding and shearing processes (*e.g.*, schist and mélange) the rock is weaker and more prone to slope failure (Rattenbury *et al.* 2006).

The overlying Waima Formation and Greta Formation (Motunau Group) are Neogene siltstones (GNS 2013). They are weak and friable. Undifferentiated Cookson Volcanic Group is predominantly basalt. It is fractured, but more erosion resistant than the sedimentary rocks into which it was intruded. Paleogene limestone and calcareous mudstone is erosion resistant, often forming prominent ridges. The sandstone, siltstone, mudstone and conglomerate formed in the late Cretaceous to Pliocene (Rattenbury *et al.* 2006). The sandstones, while weakly cemented, are relatively hard like the conglomerates. The siltstones and mudstones are softer and more prone to erosion. The clay-rich material they form through erosion are highly plastic, water saturated and are prone to slope failure. Most of the limestone and volcanic units, with the exception of the uncemented and weathered units, are strong.

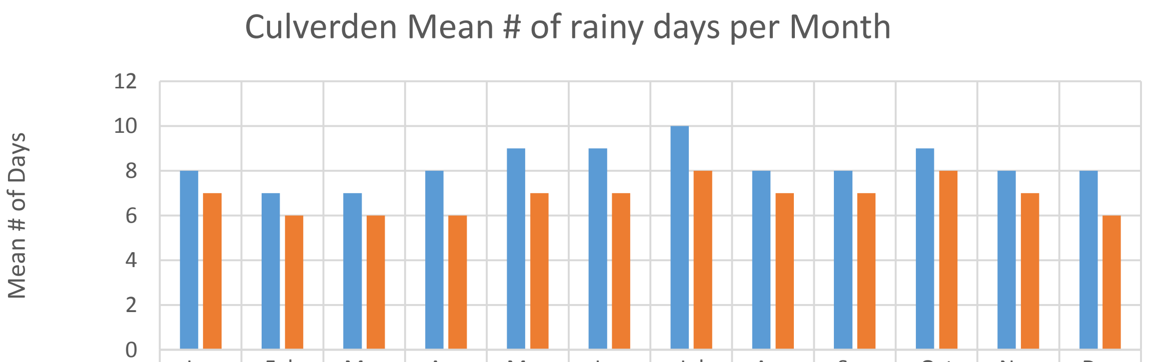
The late Pleistocene river gravels are weathered and eroded (GNS 2013). Quaternary sediments are generally weak, weathered and water-saturated (Rattenbury *et al.* 2006). Deposits with high clay content are less prone to slope failure. Loess, common in Northeast Canterbury, is usually several metres thick and has relatively high dry strength. However, loess displays tunnel gully erosion on slopes and develops debris flow with increasing moisture content.

*1.7.1.4 Regional Climate*

Canterbury has a temperate climate (Macara 2016). NIWA released a report in 2016 detailing Canterbury's climate. One of the rainfall data collection sites was Culverden, centrally located in the Hurunui District (Figure 1). Winter is the wettest season, with a high average rainfall (9 days/month) and highest number of days of rainfall (27 days) (Figure 2). This is despite the November having the highest monthly rainfall at an average of 63mm out of an annual average of 576mm (Figure 3).

Hanmer Springs, compared to four other locations in other parts of Canterbury, showed the lowest moisture deficit and highest runoff (Macara 2016). This can be extrapolated to mean that the Hurunui District has a higher soil moisture content than much of the rest of the region. As expected, and within the regional temperate trend, winter is the wettest season with most runoff and summer is the driest.

The temperature data for the Hurunui District does not have a proxy within Macara (2016)'s report. The town of Kaikōura's geography and coastal location is different from the majority of the Hurunui District. A temperature map within the report indicates that Kaikōura temperatures are typically lower on average than the Hurunui District's. The area's hilly topography creates a large degree of variability.




| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| .1mm a day | 8 | 7 | 7 | 8 | 9 | 9 | 10 | 8 | 8 | 9 | 8 | 8 |
| 1mm a day | 7 | 6 | 6 | 6 | 7 | 7 | 8 | 7 | 7 | 8 | 7 | 6 |

*Figure 2 Mean # of rainfall days per month for Culverden adapted from NIWA report using data from 1981-2010 (Macara 2016).*

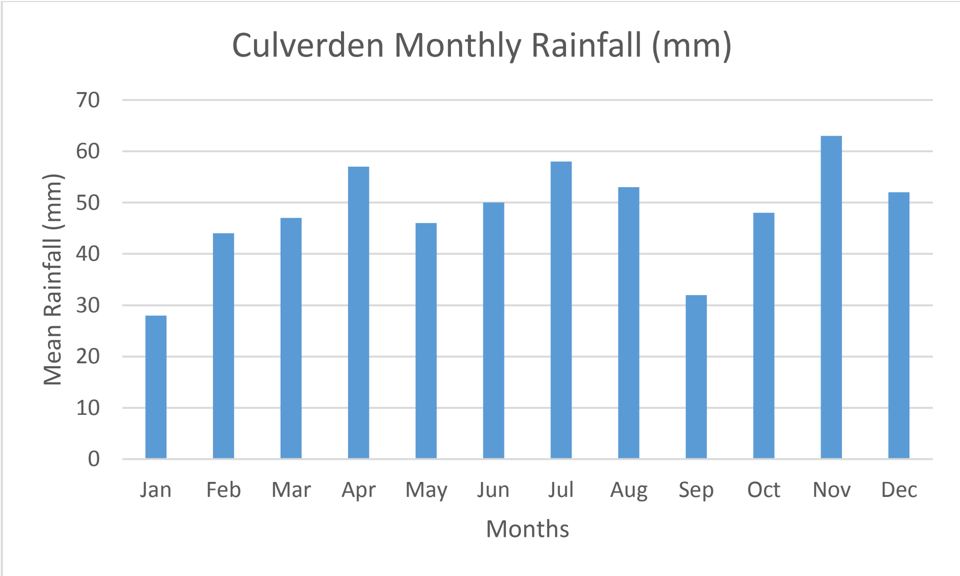



*Figure 3 Mean monthly rainfall for Culverden adapted from NIWA report using data from 1981-2010 (Macara 2016) .*

The Canterbury plains has a history of drought. The Hurunui District in particular was affected by the 1997-1998, 2000-2001 and 2015-2017 droughts (MPI 2013,2015). The drought was on-going at the time of the earthquake.

*1.7.1.5* Geohazards

The primary geohazards in North Canterbury include: landslides, earthquakes, co-seismic hazards (*e.g*., liquefaction, strong ground shaking), coastal erosion and tsunami. Coastal erosion and tsunami are not a concern for the farm case studies in this thesis as they are all located sufficiently inland. Earthquakes or heavy rainfall typically triggers landslides. They can also occur in weak shallow marine deposits originating in the Cretaceous and Cenozoic (Rattenbury *et al.* 2006). Coastal erosion and rivers undercutting slopes also trigger landslides. Hundreds of faults were mapped in North Canterbury pre-November 2016. Unconsolidated water-saturated Quaternary sediments can amplify earthquake ground motions leading to stronger shaking than experienced on a bedrock site. Such amplification has the potential to result in greater shaking damage.

Since the beginning of written human record in the Kaikōura area (about 1840), there have been many strong earthquakes (Table 1). The first of these were the **M** 7.0+ 1848 Marlborough and 1888 North Canterbury earthquakes. The North Canterbury earthquake ruptured part of the Hope Fault, which with a slip rate of 20-40mmyr$^{-1}$ is the most active fault in the area.

*Table 1 Earthquakes that have impacted the study area. Local refers to earthquakes that occurred within the 2006 Kaikōura Geological Map area. Notably the 1855 M 8.1 Wairarapa earthquake occurred on the North Island. Modified from (Rattenbury et al. 2006).*

| Rural New Zealand Earthquakes | | |
|---|---|---|
| Current Study Area | | |
| Year | Location/ Name | Magnitude (**M**) |
| 1848 | Marlborough | 7.5 |
| 1888 | North Canterbury | 7.0-7.3 |
| 1901 | Cheviot | 6.9 |
| 1922 | Motunau | 6.4 |
| 1948 | Waiau | 6.4 |
| 2016 | Culverden/ Kaikōura | 7.8 |
| Outside the Study Area | | |
| 1855 | Wairarapa | 8.1 |
| 1929 | Arthur's Pass | 7.0 |
| 1929 | Buller | 7.7 |
| 1968 | Īnangahua | 7.1 |

### 1.7.2 Hurunui District

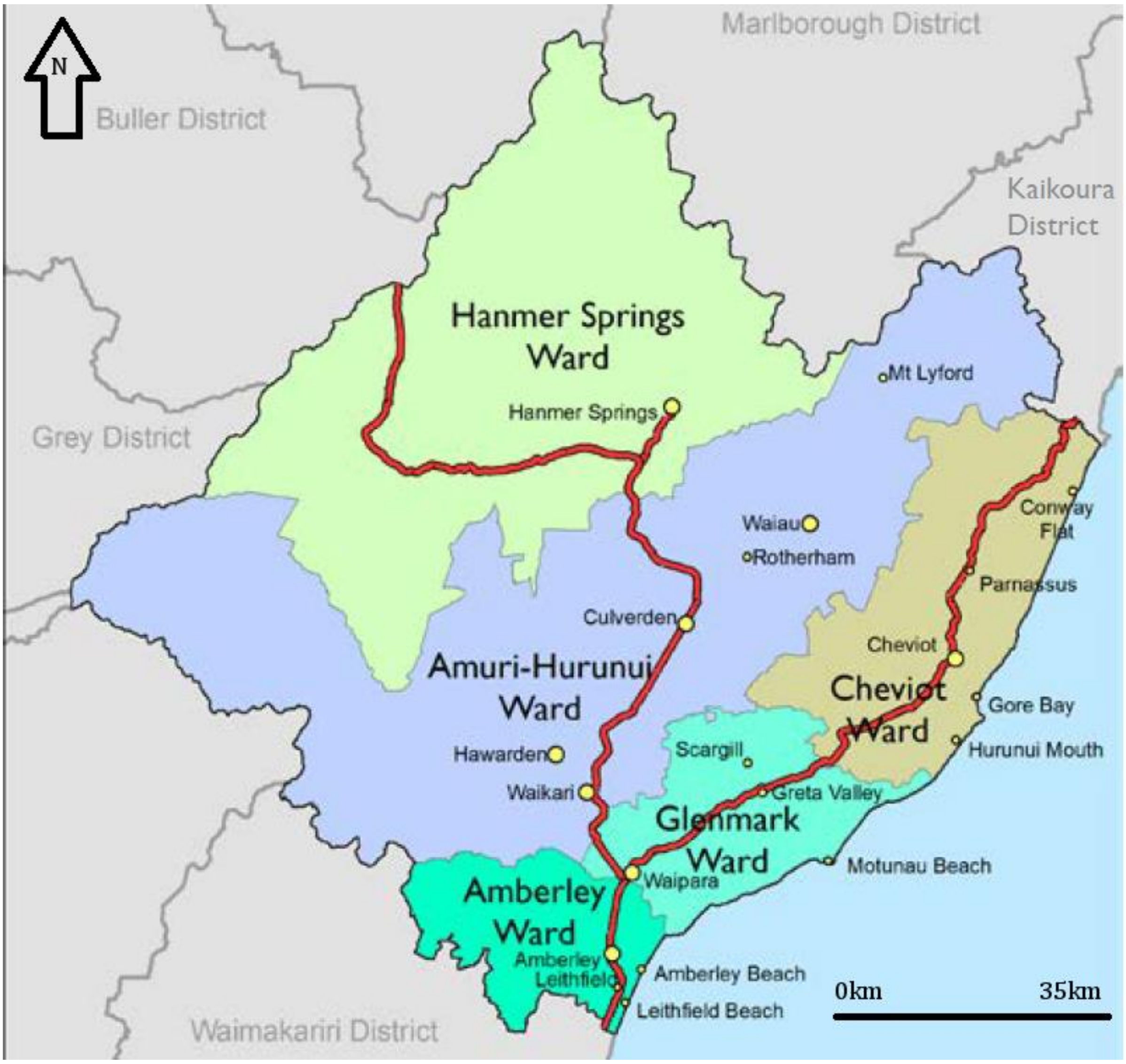



*Figure 4 The Hurunui District wards. Adapted from (Hurunui District Council, 2012).*

The Hurunui District is 864,640 ha (Figure 4)(Hurunui District Council 2012). In 2013, the population was 11,529 (Statistics New Zealand 2013b). Agriculture and forestry are the major industries. The District also has growing viticulture and tourism industries based around the areas vineyards, coastline, hot springs and lakes. The climate across the district includes coastal micro-climates and alpine climates (Hurunui District Council 2012). North Canterbury contains river valleys, mountains and ocean coastlines.

#### *1.7.2.1 North Canterbury Farming*

According to the 2012 Agricultural census, there are 993 farms in the Hurunui District (Statistics New Zealand 2013a). In 2012, a third of the farms specialise in sheep, a tenth specialise in beef, another fifteenth produce a mixture of sheep, cattle and crop and less than a tenth are dairy. The rest of the farms have other livestock or are exclusively crop. The average farm size is 420 ha.

#### *1.7.2.2 Community Support*

Farmers depend on other farmers in the community and rural organisations for support. In North Canterbury, most farmers draw some support from Beef+Lamb, DairyNZ, Environment Canterbury, EQC, Federated Farmers, their insurance companies (e.g. Farmers Mutual), local councils (*e.g.*, Hurunui District Council), the Ministry for Primary Industries and NZ Meridian.

Following the November 2016 earthquake, farmers were a significant source of support for each other. For example, there was a community organised system of relief supply flights (Small 2016). A common refrain on official releases was for farmers to check in on their neighbours.

#### *1.7.2.3 Drought*

A drought affected the Hurunui region in 2015 and 2016 (Environment Canterbury 2016). In November 2016, the region experiences significant rainfall and higher than average, for November, river flows (Environment Canterbury Regional Council 2016b). In December, rainfalls were average, which was still higher than it had been since the drought began (Environment Canterbury Regional Council 2016a). Rains in January 2017 brought some flooding in alpine areas.

#### *1.7.2.4 Previous Hurunui District Hazard Studies*

In 2000, Geotech Consulting, Ltd. completed a natural hazards assessment as part of the Engineering Lifeline Project for Environment Canterbury (Yetton *et al.* 2000). As the first of the district lifeline studies, its authors covered more than just earthquake hazards. The study covers earthquakes, floods, meteorological (*e.g.*, snowstorm, rainstorms and droughts), mass movements and coastal hazards. Yetton *et al.* (2000) did not conduct any new surveys for the study. Instead they rely on historical accounts and previous studies to create various hazards scenarios. These scenarios were single hazard focused.

Yetton *et al.* (2000) highlight earthquakes as the greatest hazard to the Hurunui District because of the wide range of effects they have over a large area and multiple systems simultaneously. The district also has the most known faults of any Canterbury district. The study based a scenario on the 1901 Cheviot Earthquake and summarised the effects over six months. An earthquake affects all lifelines. The scenario predicted weeks and months to repair the transportation networks, restoration of 90% of the power within 48 hours, a month or two to repair the water network and almost complete telecommunications restoration within a week of the event.

Flooding occurs in confined to certain areas and tied to two extreme rainfall patterns (Yetton *et al.* 2000). The north-westerly rainfall pattern, causes more hazards in the Lewis Pass, Waiau River and tributary areas. Parts of SH7 and SH1 lie in this zone. The east or south rainfall pattern affects the foothills and coast more than the north-westerly. It is more likely to impact the entirety of the district, causing slips, surface flooding and washouts. An overflow of storm water into the sewerage system is also possible.

Meteorological hazards (*i.e.*, "heavy rain, snowstorms, wind, severe local storms, including lightning and hail, and drought.") like earthquakes have wide area impacts (Yetton *et al.* 2000). Flooding and mass movements, both possibly triggered by meteorological hazards, were seen as significant enough to have their own sections. Yetton *et al.* (2000) compile the historical storm records and considered snowstorms to be the most significant, wind to be lacking in data and droughts as too slow acting to create a significant impact on lifelines.

Yetton *et al.* (2000) consider mass movements the least significant hazard due to the small area affected by each instance. Mass movement impacts transport corridors greater than any other lifeline due to their lengths. The impact is significant if the mass movement occurs at a key node location. The other lifelines can be impacted by mass movements as well when individual components or nodes are disturbed or destroyed by the hazard.

Coastal hazards include coastal erosion, tsunami, and storm surge inundation (Yetton *et al.* 2000). The impacts of these hazards are in a limited area, but can affect most of the lifeline systems.

A liquefaction study of the Hurunui District was not conducted until 2011 (Geotech 2011). The study produced a zoned map of the district to highlight areas with liquefaction potential. This is no zone with high potential and the relatively small zones that do exist are located mostly in river valleys and along the coast. Much of the district is coarse gravels, rock and soils that are not liquefiable.

#### *1.7.2.5 Water Quality*

The National Policy Statement for Freshwater Management (NPS-FM), released in 2014 to the place the 2011 statement, is a New Zealand government water reform initiative (MPI 2014). The initiative is aimed at regional councils and directs them to create objectives, limits and methods to manage freshwater. The NPS-FM falls under the Resource Management Act 1991 (RMA). It therefore works in conjunction with other National Policy Statements, National Environmental Standards, Resource Management Regulations 2010, Water conservation orders, treaty settlement legislation and the Hauraki Gulf Marine Park Act 2000. Complete implementation of the initiative is not required until 31 December 2025- with provision for extension to 2030, if deemed necessary.

The Canterbury Strategic Water Study (CSWS), first published in 2002, called for a regional water management scheme (Hurunui District Council 2012). The Canterbury Water Management Strategy (CWMS) was created out of the study in 2009, after several stages of further investigation. The Hurunui Waiau Zone Committee, the first of the Canterbury water zone committees, was formed in July 2010. The risk of community decline and death through a 'do-nothing' approach helped to prompt greater attention being placed on future proofing land-use.

"*The CWMS sets as its first order priorities: environment, customary use, community supplies and stock water; with second order priorities as irrigation, renewable electricity generation, recreation and amenity*" (Hurunui District Council 2012).

The Zone Implementation Programme (ZIP) is the Hurunui Waiau Zone Committees' recommendations for achieving the water management goals.

In 2015, the Dairy Environment Leadership Group (DELG), a partnership of various companies and groups related or part of the dairy industry released The Sustainable Dairying: Water Accord (Dairy Environment Leadership Group 2015). This Accord is the successor to the 2003-2011 Dairying and Clean Stream Accord. It lists a series of expectations and commitments from the signed parties with regards to managing waterways, nitrate loss, effluent water use, etc. This accord updated the 2013 version.

### 1.7.3 November 14th, 2016 Earthquake Sequence

#### *1.7.3.1 Overview*

At 12:02am on Monday, 14th November 2016 a **M** 7.8 occurred at a depth of 15km and 15 km north-east of the town of Culverden, Canterbury, South Island, New Zealand (Geonet 2016)(Figure 5). This initial earthquake was immediately followed by a series of fault ruptures along at least twenty-one faults from just north of Culverden to just north of Cape Campbell . Two people were killed in earthquake related incidents and more than 20 injuries were reported (Whelan 2016).

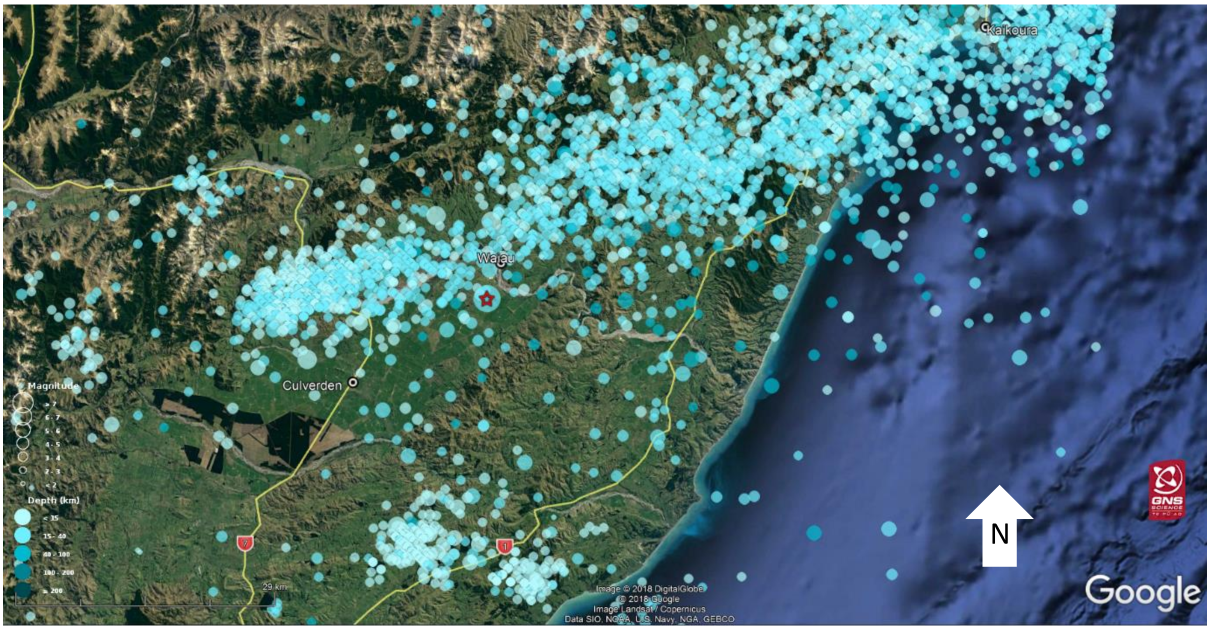



*Figure 5 North Canterbury, South Island New Zealand. The main Hurunui-Kaikōura earthquake and six months of aftershocks (14th November 2016 to mid-May 2017). Note the M 7.8 earthquake epicentre is marked with a red star. Adapted from GNS data.*

#### *1.7.3.2 Impacts on Lifelines – Essential Services*

Essential service lifelines are routes, connections and pathways that provide supplies necessary for continued production and survival. These include: telecommunications, electricity and water. The phone network was disabled due to phone line congestion and power cuts (NZ Herald 2016a). Power outages were reported throughout the area (Cronshaw *et al.* 2016). Water sheds and pipes were also damaged. The Hurunui District has thirteen council owned water schemes (Hurunui District Council 2017a). These systems suffered minor damage during the earthquake, which took several weeks to fix (Hurunui District Council 2017b).

*1.7.3.3 Impacts on Lifelines – Roads*

The initial earthquake damaged many roads. Within a few hours, NZTA closed sections of State Highway 1 and State Highway 7 due to landsliding, earthquake shaking damage, tsunami risk and geotechnical survey requirements (NZTA 2016b,c). Large sections of State Highway 1 remained closed as of June 2017 due extensive landsliding, subsidence and damaged bridges and infrastructure (NZ Herald 2016a). Re-establishing an access route for Kaikōura and the large trucks stuck in the Picton, the ferry port from the North Island, was a major priority for NZTA. The inland road from Culverden to Kaikōura was temporary closed due to aftershock risks and time needed to survey for damage (NZTA 2016a). Limited access was granted in the first few days after the earthquake. Aftershocks and rain-triggered mudslides led to occasional closures in the months after the initial earthquake.

*1.7.3.4 Effects on Farms*

Many dairy farms were forced to dump their milk in the weeks after the earthquake due to poor road conditions blocking milk truck access (Dennett 2016). If cows are not milked, they will dry off or develop mastitis. Some farmers had insurance for events like this and the milk Company Fonterra reportedly worked directly with their effected farmers. Graham Collins, a Kaikōura dairy farmer, told stuff that the 1993 flood and 1975 'wind storm' were not as severe as the November earthquake. Many farmers turned to neighbours to borrow generators and use dairy sheds (2016b). The earthquake occurred during peak milk production time.

*1.7.3.5 Post-Disaster Recovery Frustrations*

Some farmers expressed frustration with Civil Defence's lack of focus on animal welfare and farm recovery (Hill 2016). 'Team Ag', a consortium of local and national rural organisations was formed to address this issue. Advocates for the consortium emphasised its people's understanding of farmers' emotions and situations (i.e. their home and workplace are often the same). Road closures were another source of frustration with civil defence. The closure of the Inland Road from Waiau to Kaikōura to all, including local residents and essential service repair teams was particularly frustrating to Mt. Lyford locals (Broughton 2016). The decision was made by someone stationed in Christchurch, not locally. This situation typified the disconnection between inter-post disaster recovery groups.

After the earthquake, there was greater governmental and media focus on Kaikōura. Helicopters traveling to Kaikōura reportedly flew over many isolated farms, without stopping to check in on the farmers (Cook 2016). Isolated farmers are typically capable of being self-sufficient, but the sudden lack of communication and drain on their resources was stressful. Helplines cannot help people who cannot call in. One official advised calling in an ask for assistance for neighbours who were unable to do so for themselves (Cook 2016).

#### *1.7.3.6 Relevant Post-Earthquake Sequence Legislation*

The Hurunui/Kaikōura Earthquakes Emergency Relief Act 2016 received royal assent on 5th December 2016 (2016). The Act allowed for a temporary relaxation of the resource consents and emergency powers under the Resource Management Act (RMA), explicitly for repairs related to this earthquake sequence. The Act was designed to assist communities and councils in the earthquake-affected area to recovery, specifically economic, and to plan, rebuild and restore and improve buildings, infrastructure, and economic, social and cultural well-being.

#### *1.7.3.7 Post-Earthquake Sequence Funding for Farmers*

Several funding sources were setup or repurposed post-earthquake sequence to assist farmers and rural communities rebuild and plan for the future. The Primary Industries Earthquake Recovery Fund is a $5 million support fund (MPI 2017d). The Fund is in two parts: part one is a community group project application and part two is an advisory services fund. The applications for the community projects were collected between 10th May and 23rd June, approved on 31st July, announced on 3rd August and contracted on 31st September. Eight projects were approved for a collective total of $3,542,920 (MPI 2017a). Part two is enacted by farmers' approaching approved contractors. The MPI will pay the $5,000 grant directly to the contractor.

The government made use of industry resources and structures to support, drive and run initiatives. MPI also created a skilled farm workers initiative to support farm recovery during the first six months (Guy 2017). The initiative utilised the Federated

Farmers' 0800 FARMING line. Both Agriculture Employment Services Ltd (AgStaff) and Federated Farmers were contracted to manage the initiative. This initiative was funded with $600,000 (MPI 2017b).

The Kaikōura Earthquake Relief Fund was $4 million fund for primary production industries to cover restoring uninsurable infrastructure and initial clean-up costs (MPI 2017c).

## 1.8 Thesis Format

The thesis structure had been designed to address each of the objectives listed in Section 1.3.2 in a clear and logical manner. **Chapter 2** details methodology used to develop the case studies. **Chapter 3** presents the basic characteristics and timelines for each case study farm. **Chapter 4** discusses the major themes developed from the analysis of the case studies. **Chapter 5** contains a thesis scope, conclusions summary, list of recommendations developed from the study and suggested future work.

# Chapter 2 Research Methodology

## 2.1 Introduction

In order to begin to address the gap in farm-level earthquake impact knowledge, an in-depth qualitative case study approach was chosen. Three farms, known to have been significantly impacted by the 14th November 2016 earthquakes, were approached to participate. Two rounds of semi-structured interviews were used to capture the farms' earthquake stories as they changed over time. The semi-structured question sets were generated from an initial literature review. A multi-disciplinary approach of media analysis and geological data review supplement the previous literature and interviews. A general inductive approach was used to analyse the common themes developed from the interviews. From these themes, the factors that influenced the earthquake impacts and recovery of the farms were identified.

## 2.2 November Earthquake Interviews

### 2.2.1 Ethical approval

A low risk application was submitted to the Human Ethics Committee on the 21st June, 2017. The application went through two rounds of refinement (emailed on the 11th July and 20th July) before being approved on 31st July 2017. The semi-structured interviews were designed so as to not contain culturally offensive or distressing material, and interviewers remained mindful that this could have been a distressing event for some people. Three main forms of distress mitigation included: constraining interview topics to impacts to farm infrastructure and essential services, having at least one researcher with experience in post-disaster contexts present for the interview, and recruiting by word of mouth and personal networks – which allowed judgement of participant selection. Participation was entirely voluntary and all data recorded remains confidential. Information sheets were used to draw participants attention to the risks associated with participation, and to clarify that although identifying details of individuals and farms would not be included in any publications based on this data, the small sample pool made total anonymity difficult to achieve. Consent was gained after participants had discussed this risk with interviewers.

### 2.2.2 Interview Participant Selection

The interviewees were a purposive sample of Hurunui District farming community chosen as representative of the broad farming categories and topographies typical of Hurunui District discussed in the (Section 1.7.2.1 ). This study focused on the Hurunui District because the University of Canterbury was actively involved in mapping the coseismic earthquake impacts in the area at the time of project inception. The decision to limit the interviewee sample to three farms was to allow for in-depth analysis for approximately a year-long recovery period. All three farms were significantly impacted by the coseismic effects of the 2016 earthquakes and foresee various stages of recovery lasting years.

Interviewees were invited (by phone or email) to participate in the interviews. A convenient time and location for the interview was arranged. All participants chose to be interviewed on their farms. A consent form and information sheet (Appendix C) was provided (by email) to the participant ahead of the interview and again at the beginning of the interview (in a hard copy). To protect the identity of the participants, each farm was assigned a letter identifier. Farm A is an extensive hill country sheep and beef farm. Farm B is a medium-sized steep hill sheep and beef farm. Farm C is a relatively small flat river terrace dairy farm. Where use of specific names risks confidentiality, the names of outside organisations (*e.g.,* government departments and NGOs, have been replaced with a generic name as another measure of confidentiality. The Ministry of Business, Innovation and Employment (MBIE); the Ministry of Primary Infrastructure (MPI); Environment Canterbury (ECan); Civil Defence and Emergency Management[1] (CDEM) and the local council are [The Government Department]. The Earthquake Commission (EQC) and private insurance are [Insurer]. Any names are replaced with occupations.

### 2.2.3 Semi-Structured Interviews

Two rounds of semi-structured interviews were conducted, in August 2017 and January 2018. The two rounds were designed to allow for follow-up questions that stemmed from first round analysis and to capture the recovery and hazard impact changes over a longer period of time. In total a 14-month recovery timeline was captured. The semi-structured approach was chosen to allow for participant driven conversation within the

[1] CDEM may refer to the Ministry of Civil Defence and Emergency Management (MCDEM), Canterbury Civil Defence and Emergency Management (CCDEM), Hurunui CDEM and many other organisations.

bounds of the project's objectives. The interviewer's lack of farming knowledge and the limited number of comparable case studies informed this decision because there were likely to be relevant topics and ideas that had not occurred to the interviewer prior the interview. The interviews took place on each of the farms and were of a one to two-hour duration. The first round of interviews focused on capturing the farms' status at the time of the earthquakes and all the impacts that stemmed from them over the intervening nine months. The second round focused on follow-up questions from round one, changes over the intervening five months and the future of the farms.

### 2.2.4 Research Questions

The following are the high-level questions used to explore the thesis' objectives of investigating the farm-scale earthquake impacts to infrastructure and essential services with the perspective of change over space and time. These questions were rewritten into a four section set of more detailed interview questions. The sections were shaped to capture temporal changes and draw on previous agricultural hazard impact studies (Section 2.2.5 ).

- How do farm characteristics (*e.g.*, size, farm type and topography) influence the earthquake impacts?
- What was the status of each farm at the time of the earthquake?
- What, if any, are the disruptions to each farm's annual calendar?
- What were the initial impacts of the 2016 Kaikōura/ Hurunui earthquakes on the farms?
    - What are the various components of on-farm infrastructure and how are the impacted?
- What were the direct and indirect impacts to each farm from cascading hazards stemming from the 2016 Kaikōura/ Hurunui earthquakes?
    - What do cascading hazards look like at farm-scale and how can that data be captured?
- What impact did NGO and government initiatives have on farm recovery?
- What land-use/ business model changes are farms considering post-recovery?

### 2.2.5 Semi-Structured Interview Question Set Development

The question sets were developed in advance of the interviews using previous rural hazard impact studies as guidance. The first round of questions focused on capturing each farm setting pre-earthquakes, the initial earthquake impacts and the first nine months of post-earthquake recovery. Four sections were used to guide interview to address the research questions (Section 2.2.4 ).

The first question section was developed to capture the farm characteristics. This covered everything from a farm's basic characteristics (*e.g.*, topography, livestock type, personnel) and annual calendar to its infrastructure and essential service assets. The studies of Almond *et al.* (2010) and Whitman *et al.* (2013) from the 2010 Darfield earthquakes, and Craig *et al.* (2016b), a study on long-term volcanic ash impacts to agriculture, emphasise the contribution of farm characteristics and event time to impact severity and farm vulnerability.

The next section of questions was designed to capture the farm and the farmer's previous experiences with hazards. These questions stemmed from the concept of cascading hazards, specifically investigating the part the farm and farmer's experience with hazard events influence the impact from subsequent hazard events. Craig *et al.* (2016a), Farmar-Bowers & Lane (2009) and Berkes (2007) all discussed the influence of pre-existing conditions (*e.g.*, droughts, financial hardship) on vulnerability and farmer/local hazard experience on recovery.

The third section of questions was aimed at capturing the timeline of events and their impacts on the key physical assets named in the first section of questions. This began by asking the farmer to recount the events in their own words starting with the earthquake. These questions were shaped by the studies of Whitman *et al.* (2012),(2013) which discussed both the physical earthquake impacts to farms and mental/emotional earthquake impacts to farmers. The discussion of Craig *et al.* (2016b) on the relationship between on essential service and livestock characteristics and hazard impacts were also drawn on. Recovery factor questions covering outside help, community resilience and farm-scale decision making were influenced by the study of Darnhofer (2010) on farm resilience.

The final section was designed to capture non-physical impacts as well as providing some insight into what the farmer thought the future of the farm might look like. This included changes to the farm plan and economic impacts. These questions were shaped by the concept recovery's time cost (Mohan & Strobl 2016) and studies about the various factors involved in land-use changes and farm recovery (Farmar-Bowers & Lane 2009; Saunders & Becker 2015).

The second round of interview questions varied between the farms. For the most part, they were follow-ups to the questions from round one. This began with general questions about impacts and recovery changes over the intervening five months. This was followed by a section on drought and government aid questions was developed from the collective round one responses. The second round interviews ended with specific questions regarding the contents of their responses designed to capture aspects of impacts and recovery that had not been addressed fully in first round interview.

### 2.2.6 Data Collection and Processing

Two researchers were present for every interviews. The presence of a second researcher (at least one of the supervisors – one of whom was raised on a farm in Canterbury) was to reduce the chance of causing inadvertent moral or cultural offence. The interviewer and questions were substantially prepared before the interview with regards to the cultural aspects to be aware of. The interviews were audio recorded to reduce the possibility of misunderstandings and allow for post-interview clarifications and corrections. All recorded notes (notebook, audio recordings and electronic files) were kept securely in locked room or vehicle (while traveling). Electronic data was stored on-campus on a desktop computer and in a portable hard drive, which was kept in a locked office or on the researcher's person. Data on laptops was deleted after transfer. At the completion of the project all the data (both written and electronic file) was handed over to a supervisor for secure keeping for a period of 5 years, after which it will be destroyed. The interviewees were referred to by a letter assigned to their farm, or their occupation (e.g. Farmer A, Farmer B, etc.). Given the small area in which the interviewees are being selected and the size of the farms, it is improbable that the identities of the interviewees will be kept completely confidential. After the audio recordings were transcribed, they were sent to the participants for review, comment, clarification and approval.

### 2.2.7 Transcription

Within two weeks of each interview, a transcript of the interview was produced. This transcript was sent to the participants to check for accuracy and completeness. The participants then had thirty days, time period flexible if participant requested, to review the transcript and send back their comments, clarifications and requests for deletions.

### 2.2.8 Interpretation of interview results

This study uses a general inductive approach as outlined by Thomas (2016). This approach was selected because the volume of raw text data was the equivalent of over nine hours of audio recording. Summarising these data. It allowed for comparison between different sections of the transcripts. This approach also allowed for the development of themes addressing the research questions.

The first step of the general inductive approach was to send the prepared transcripts to be reviewed by the participants. After the reviewed transcripts were returned, the inductive coding process began. The transcript texts were read thoroughly. Each distinct quote section from the transcripts was entered into a spread sheet and summarised (Table 2). Then most sections were assigned at least one theme. If a sections displayed multiple themes, the row was duplicated. Some sections were deemed outside the scope of the study and not assigned a theme. A second level of theme assignment was conducted to reduce the number of individual themes, which numbered over one hundred. Finally, these revised themes were condensed to the five categories that encompassed the various aspects of the analysis. The benefits of iterative organisations of themes and sub-themes allowed for adaptation as appropriate as new themes or factors emerged from later interviews. Use of the spread sheet allowed for easy inclusion.

*Table 2 General inductive coding headings and category descriptions. The transcript data was entered into an excel spreadsheet as block of quotes. They were then summarised and assigned themes.*

| Quotes | Interview | Extract | Summary | Stage (S0, S1, S2, S3, S4) | Theme | Supertheme | Damage to Infrastructure | Damage to Infrastructure Comments | Infrastructure Damage Impacts | Comment |
|---|---|---|---|---|---|---|---|---|---|---|
| Quote # | Interviewee Identifier | Quote | Summary | Period of event (Pre, During, Immediately after, Short-term, Long-term) | Theme | Theme Category | Yes/ No | How was the infrastructure damaged? | Which infrastructure was damaged? (standardised for sorting) | Questions/ Thoughts |

The trustworthiness of the interpretations was evaluated through stakeholder checks (Thomas 2016). The stakeholders for this study are the interview participants. The participants were sent copies of their transcripts to review before analysis was started.

The participants were also provided a copy of the executive summary for this study before thesis completion.

### 2.2.9 Multi-disciplinary Approach

In addition to the semi-structured interviews, peer-reviewed literature and secondary data available in public domain (*e.g.*, media reports, blogs) were reviewed.

Before the interviews, a timeline of the earthquake recovery was collated from a variety of news outlets, government and NGO websites.

The latest available fault trace and landslide maps were examined and capture the types and amounts of damage to each property. Soils and geology maps were consulted for an indication of liquefaction and landslide probability, and shaking intensification.

Recovery news, and the concerns of the farming community in general, has been followed over the course of the project. One highlighted concern is a mycoplasma bovis outbreak. Although not directly related to the earthquake, situations like these highlight the problem of livestock safety/security with on-going landsliding and fence damage. The issues become more than financial, they are also water quality and biosecurity issues.

## 2.3 Methodology Summary

An ethics application was submitted to the University of Canterbury Human Ethics Committee and approved on 31st July 2017. Peer-reviewed literature, grey literature (media and government reports) and geohazard data produced by University of Canterbury researchers were drawn from to develop a set of research questions. Farmers on three Hurunui District farms, representative of the various topographies and farming types present in the district, were approached and agreed to participate in two rounds of semi-structure interviews. Transcripts were produced from audio recordings of the interviews. After the participants reviewed and approved their transcripts, a general inductive approach analysis was applied (Thomas 2016). The transcript text was divided into sections, summarised, assigned to themes and categories. The hazard impacts, recovery factors and recommendations were developed from the results of this analysis.

# Chapter 3 Case Studies

## 3.1 Introduction

About half of land area of the Hurunui District is farmland (Statistics New Zealand 2013a). Dairy farms are mostly confined to the flat river terraces and the hilly, mountainous areas contain sheep, arable and beef cattle farms. Across the Hurunui District, most of the surface ruptures, landslides and other ground deformation from the 14th November earthquakes were on farmland (Dellow *et al.* 2017; Stirling *et al.* 2017). University of Canterbury geologists mapping these features spoke to the farmers on whose land they were working (C. Fenton, University of Canterbury, *pers. comm.*, 15th February 2017). They learned not only about the initial damage to these farms, but also about a series of on-going hazards (*e.g.*, landslides and flooding) stemming from the initial earthquake. Previous literature regarding earthquakes tends to focus on urban area impact and recovery as historically sparsely populated area earthquake have been deemed insignificant (Reitherman 2006). Whitman *et al.* (2012) studied the impact of the 2010 Darfield earthquake on rural organisation, including farms, exclusively on the Canterbury plains; this geographic locale made on-going, or cascading, hazards less likely than in more complex terrain. Even so, there are many similarities between the two farm communities' experiences. To understand the differences, the work of (Craig *et al.* 2016a, 2016b) on volcanic impacts on agriculture were consulted. This deals with the influence of pre-existing conditions, such as drought, and farm characteristics on hazard vulnerability. To date there is a significant lack of studies on earthquake impacts at a farm-scale. This thesis draws on studies of other hazards at a farm-scale to create several farm case studies for the 14th November earthquakes.

This chapter summarises the case studies compiled for this thesis. Section 3.2 covers the case study characteristics. Each subsection covers a different asset of the case studies, first in a comparison chart and then in a summary that highlights the key points.

## 3.2 Case Studies

### 3.2.1 Farm Contexts

This section discusses the basics of the farm characteristics, assets and impacts. Section 3.2.1.1 covers the geological and geographical characteristics of the farms and their coseismic hazard influences. Section 3.2.1.2 covers the farms' prior hazard experience and their contributions to farm resilience and vulnerability. Section 3.2.1.3 covers earthquake impact variations due to farm types and workforce types. Section 3.2.1.4 covers the farm's physical asset (infrastructures and essential services) and their damage.

### *3.2.1.1 Case Study Farms' Physical Descriptions*

The physical aspects of the case studies' land determined the types and magnitudes of coseismic hazards that impacted each farm in relation to the 14th November earthquake (Table 3). The three farms display three different topographic profiles. This appears to be a key factor in different experiences of cascading hazards stemming from the earthquake. Some of this information was garnered from the interviews. Others was sourced from public records and maps.

*Table 3 Physical data for Case Study Farms A, B and C. Size and topography information pulled from interview data. Soil description sourced from (LINZ n.d.) and geological description sourced from (GNS 2013).*

Case Study Farms' Physical Descriptions

| | Size | Topography | Elevation variability | Soil | Geology |
|---|---|---|---|---|---|
| Farm A | ~2000ha | Hill country, mountains, hills, valleys, small flats | Min. elevation ~230m, Max. elevation >900m | slightly to moderately deep imperfectly draining silty loam and moderately well-draining loam | Siltstone, sandstone, limestone, river gravels |
| Farm B | ~700ha | Steep hills, ~10% small flats | Min. elevation ~185m, Max. elevation ~300m | slightly deep imperfectly draining silty loam and well-draining sandy loam | Siltstone, sandstone, mudstone, river gravels |
| Farm C | ~500ha | Flat river terraces | Min. elevation ~167m, Max. elevation ~179m | moderately deep well draining silty loam | River gravels, sands, silts |

Topography and soil and bedrock characteristics provided the greatest influence on the types and magnitudes of hazards impacting each farm. Amplification of seismic waves due to varying ground conditions was seen in both the 2016 Hurunui/Kaikōura and the 2010/2011 Christchurch earthquakes (e.g., Kaiser AE *et al.* 2014). Similar to the Port

Hills affected by the 2010-2011 Canterbury earthquake sequence, Farms A and B are located in hilly areas with variable soil cover. Hills and ridges produce strong topographic amplification of earthquake ground motions. This correlates with the higher levels of infrastructure damage observed on these properties. Farms A and B also have steep slopes contributing to higher levels of landsliding and related ground deformation. Slope failure on Farm C was confined to river terrace edges and related ground deformation, while present, was relatively minor. Soil with the potential to liquefy is generally loose and sandy, located near-surface and saturated. These conditions are generally limited to on or near current river floodplains. Only Farm C reported experiencing liquefaction. A large portion of land has high liquefaction potential, which matches the assessments from pre-earthquake susceptibility maps. Farms A and B had low potential for liquefaction due to the predominant soil type and low water content. Even the adjacent river floodplains comprise gravels which have a low susceptibility for liquefaction. The initial coseismic hazards on each farm varied due to proximity to the primary fault rupture, the underlying bedrock geology, topography and soil type.

#### *3.2.1.2 Farm hazard histories*

The previous hazard experiences of the farmers and farms shape the way they react to and are impacted by the earthquakes (Table 4). None of the farmers had experienced an earthquake impacting their farm before. However, they were aware of the proximity of several major faults. The experiences from previous natural hazards increased the farmers' resiliency and provided mental context for the damage caused by this sequence of earthquakes.

*Table 4 Previous natural hazard experiences of each farm. These were gathered during the interviews.*

Hazard Histories

| | Farm A | Farm B | Farm C |
|---|---|---|---|
| 1922 | - | M6.4 Motunau earthquake triggered landsliding | - |
| 1923 | - | Cyclone reactivated large landsliding | - |
| 1992 | Snow storm | - | - |
| 2015-2017 | Drought | Drought | Drought |
| Annual | Snow storms, rainstorms (Nor'westers), landsliding | Snow storms, rainstorms (Nor'westers), landsliding | Snow storms, rainstorms (Nor'westers), historic flooding |

Most of the previous hazard events recounted by the farmers were weather related. Snowstorms and rainstorms (Nor'westers) are frequent winter events that leave the farms without power for several days. In response, the farms have prepared to run without grid electricity for extended periods of time. A drought heavily impacted Farms A and B for three years before the earthquake. The farmers reduced the number of stock on Farm A in order to compensate for the reduced grazing. They do not use large-scale irrigation to maintain year-round grazing. On the drought impact to the livestock, a farmer commented:

> *"Three years of below average rain is the most recent activity. That has had a cascading effect because we had less animals when the earthquake hit. We were probably down 25 to 30 percent of our normal carrying capacity."*

Rather than aggravating the effect of earthquake impacts, this decrease meant that economic losses were reduced. They also let go their part-time help, which helped economically, but put heavy strain on the farmer and their family as they picked up the full-time workload. The farmer commented that this was simply part of farming life:

> *"Family farming in New Zealand is a tale of survival. When drought hits you lose a lot of money and have to work harder and longer than before. During the recent drought I had to lay off our helper and worked 7 days a week for 9 months [.] But our land is precious to us it's our Tūrangawaewae, its worth fighting for. our children are 5 generation, they are aware of the struggles and accept that its part of living here, it's good for them to know that tough times are ahead. My wife and children did a massive amount of unpaid work during the drought."*

The Farm B farmers' strategy was to send their animals off farm for winter grazing. A coexistent downturn in dairy payouts increased available grazing land in the region.

Following the earthquakes, they were unable to repeat this drought strategy and struggled to adjust.

Farm C has suffered historical flooding. The frequency of flood events used to be twice a year and a ten-year flood. The flood impacts were limited to grazing areas and fencing damage. As part of a community flood protection scheme, the farmers have built flood mitigation and put in planting that have reduced the frequency of floods.

Both Farms A and B also have experienced annual landsliding and large historical landsliding. Most of the annual landsliding is induced by winter rain and is an expected occurrence. This pattern did not hold for the earthquake, creating frustration. A farmer found that slips occurred in new places:

> *"I have seen 12 inches of rain in one day. That was a really significant rainstorm that created land movement. But that was more in places that you thought would slip. You know, steep slope with say little vegetation. Whereas, at the moment I drive 'round and go 'why the heck didn't you move? And you did?' That's what I find interesting. And really annoying."*

Although the farmer on Farm B had not experienced earthquakes effects, the farm had. An April 1923 cyclone reactivated a large landslide that had been triggered near the main dwelling by the 1922 M6.4 Motunau earthquake. The farmer was concerned that the 2016 earthquakes would reactivate this area of landsliding. This slope had issues as recent as 2004 when water seepage was observed. The family evacuated from the homestead and later investigations of the site concluded that the landslide had reactivated and the homestead was at risk. A farmer described the large landslide's history:

> *"There's already historic landslide beside the house. That was triggered after an earthquake in Motunau in 1922 or 23 [it was 1922]. And we had a massive rain event here in April of 19-, whatever year the earthquake was, the following year we had a massive rain even in April. We had 357 ml, I know that we had 700ml over that month. Because of the recordings, that was in 1924 I think is was [it was probably 1923] the recording back then recorded a month. We don't know how much we got in one day or three days. At that time of the year, I'm imagining it's a cyclonic event. Because March, April here in Canterbury or along the east coast we can get big tropical storms come in. The start in a south-easterly, north-easterly circle and then wherever they decide to sit they'll dump. And we get those quite often here. And that's my guess as to what was triggered in April. So, the hill's rattled. It's got some loosing of sediments. And the rains got into it."*

Farmers gain relevant experience from hazard events because of what they can reveal or influence the farms' hazard susceptibility. The annual cyclone and winter seasons have prepared farmers to manage their farms without essential services, such as power, provided from off-farm sources.

#### *3.2.1.3 Type of farm, size, workforce*

The three farms represent different parts of the farming spectrum in the Hurunui District (Table 5). Their farm types, irrigation usage and hired staff influence how the farms were impacted. Their recovery priorities and resources also differed because of these factors.

*Table 5 Farm Type Characteristics. The stock class, presence of irrigation and on-farm workforce influenced initial impacts and recovery decisions. Note: part of Farm C is unirrigated.*

Farm Characteristics

| | Stock | Irrigation | Staff |
|---|---|---|---|
| Farm A | Sheep, beef cattle, bees | No | Seasonal employees |
| Farm B | Sheep, beef cattle, bees | No | 1 Full-time winter employee, seasonal employees |
| Farm C | Dairy cows, beef cattle | Yes | 10 Full-time employees |

Farms A and B are winter wet, summer dry farms, which means they are not irrigated and instead rely on the natural climate patterns to provide enough water for crop and fodder growth. Most of Farm C is irrigated. Its dry stock are kept on a section of unirrigated land called the runoff.

Farms A and B hire contract or seasonal workers for drilling, weed removal and shearing. These jobs typical take a couple of days and workers on Farm B take care of their own accommodation and travel. Before the earthquake, Farm A provided accommodation in the shearers' quarters. Seasonal workers' time on farm is typically weather dependent. For example, wet weather increases the length of time required for (seed) drilling. Farm A used to hire a part-time on-farm helper, but they let them go during the drought. The workload was picked up by the farmer and their family. Farm B hires a full-time worker from mid-April to the start of August every year to do maintenance during the winter season. Before the earthquake, Farm C had around ten full-time staff members who were mostly housed on-farm. Following the earthquake, all but one staff member was let go. The farm has since partially re-staffed. As of January 2018, although the farm had returned to full operation, it was understaffed due to damaged staff accommodation.

Farm C, as a dairy farm and the largest full-time employer, was initially the most severely impacted by the earthquake. The immediate loss of functionality of their dairy shed put their cows at risk of developing life-threatening health problems. Swift relocation of the dairy herd saved their livestock. However, the loss of the dairy shed and staff housing damage reduced their ability to continue to employ their staff. The impact to staff on Farm B was less severe as their employment was mostly seasonal and their housing was off-farm. Only the timing of major jobs, impacted by the earthquake, on Farm B was changed.

Farm A lost its shearers' quarters and thus the ability to house staff on-farm. However, like Farm B, it mainly only hired seasonal employees, thus the impact to farm operation was minimal. Even so, the loss of the shearers' quarters has limited the ability to bring in contractors for farm tasks and repair work. The repair speed of their other infrastructure and essential services has, in part, suffered as result.

*3.2.1.4 Farm infrastructure and essential services*

All three farms have vital infrastructure components that are necessary for the daily running of the farm (Table 6). Each farm also relies on essential services (water, power, telecommunication and transportation). Primary economic infrastructure is a farms' currently active complex that is essential for its main money producing activity. The farms have various types of housing (the main homestead and staff housing). Other infrastructure includes any other physical construction on the farm (*e.g.*, fences, silos, stockyards). The organisation and resiliency of each of these components varies between farms.

*Table 6 The physical assets of farms are essential infrastructure and essential services. The primary economic infrastructure refers to the building or complex that is the main source of production on-farm. Essential infrastructure are the buildings and complexes. Essential services are the on- and nearby off-farm lifelines.*

Case Study Farm Essential Infrastructure and Services

| | Essential Infrastructure | | | Essential Services | | | |
|---|---|---|---|---|---|---|---|
| | Primary Economic Infrastructure | Housing | Other Infrastructure | Water | Power | Telecommunication | Transportation |
| Farm A | Woolshed | Homestead; Shearers' quarters | Fences, sheds, silos, stockyards | On-farm pumps | MainPower, small generator, gas backup | Spotty landline and poor mobile phone reception | Far main off-farm road, tracks |
| Farm B | Woolshed | Homestead | Fences, stockyards | County water schemes | MainPower, gas backup | Strong mobile phone reception | Close main off-farm road, tracks |
| Farm C | Dairy shed | Homestead; 5 Staff houses | Fences, old woolshed, stockyards, irrigators | On-farm wells | MainPower, large generator | Spotty landline and strong mobile phone reception | Close main off-farm road, tracks |

Farm B is on the county water scheme. This is a gravity fed system sourced from the Waiau River. The water is stored in several reservoirs and tanks on the property. The farm received around 12 or 13 units a day. Each unit is 1800 litres, which equates to a total on-farm use of about 21600-23400 litres a day. The farm uses dams at the base of gullies to act as sediment traps for storm water. The county water scheme was badly damaged by the earthquake when many water tanks located on high ridges and buried water pipes were damaged (Hughes *et al.* 2017) .

The water sources for both Farms A and Farm C are located on their properties. Farm C has a couple of shallow wells due to its proximity to the Waiau River. Before the earthquake, Farm C had a generator powerful enough to run the dairy shed or the irrigation system. The generator allowed them to restore their water access before the main powerlines were repaired. Farm A gets its water by pumping from springs on the property. Much of this infrastructure was damaged during the earthquake. A new system took several months to install.

All of Farm A's main buildings are clustered together with the stockyards on the only flat section of land. Farm C's main buildings are clustered near the river. Farm B's main infrastructure is also clustered in a small section of the farm, but they also have stockyards strategically spread throughout the farm to reduce time lost to stock movement.

Farm C's dairy shed repair was more urgent because it is used daily 10 months of the year compared to Farms A and B's woolsheds which are used for several days 1 to 3 times a year.

Without infrastructure a farm is just a piece of land. A farm's ability to be economically viable and perform the basic tasks of animal husbandry are reduced when vital infrastructure and services are damaged or disrupted. The various farm infrastructure found on each farm reacted differently to the earthquake shaking and coseismic hazards. The observed variations in damage were a result of infrastructure location, ground conditions and construction materials. The daily reliance on the dairy shed on Farm C, versus the seasonal use of the woolshed on the other two farms, raised the repair urgency at this location. Essential services were impacted across all three farms, but recovery rates varied based on farm location and essential service source. Regardless, all three benefits from having lifeline backup systems, such as generators.

#### 3.2.2 Annual Calendar

The annual calendar for a farm contains all of the important farming activities (Figure 6). These include animal husbandry (*e.g.*, lambing), crop-related (*e.g.*, drilling) and other maintenance tasks. These are frequently seasonal and variously weather dependent tasks. The earthquake in late 2016 and the weather events in 2017 impacted the occurrence and timing of many of these tasks.

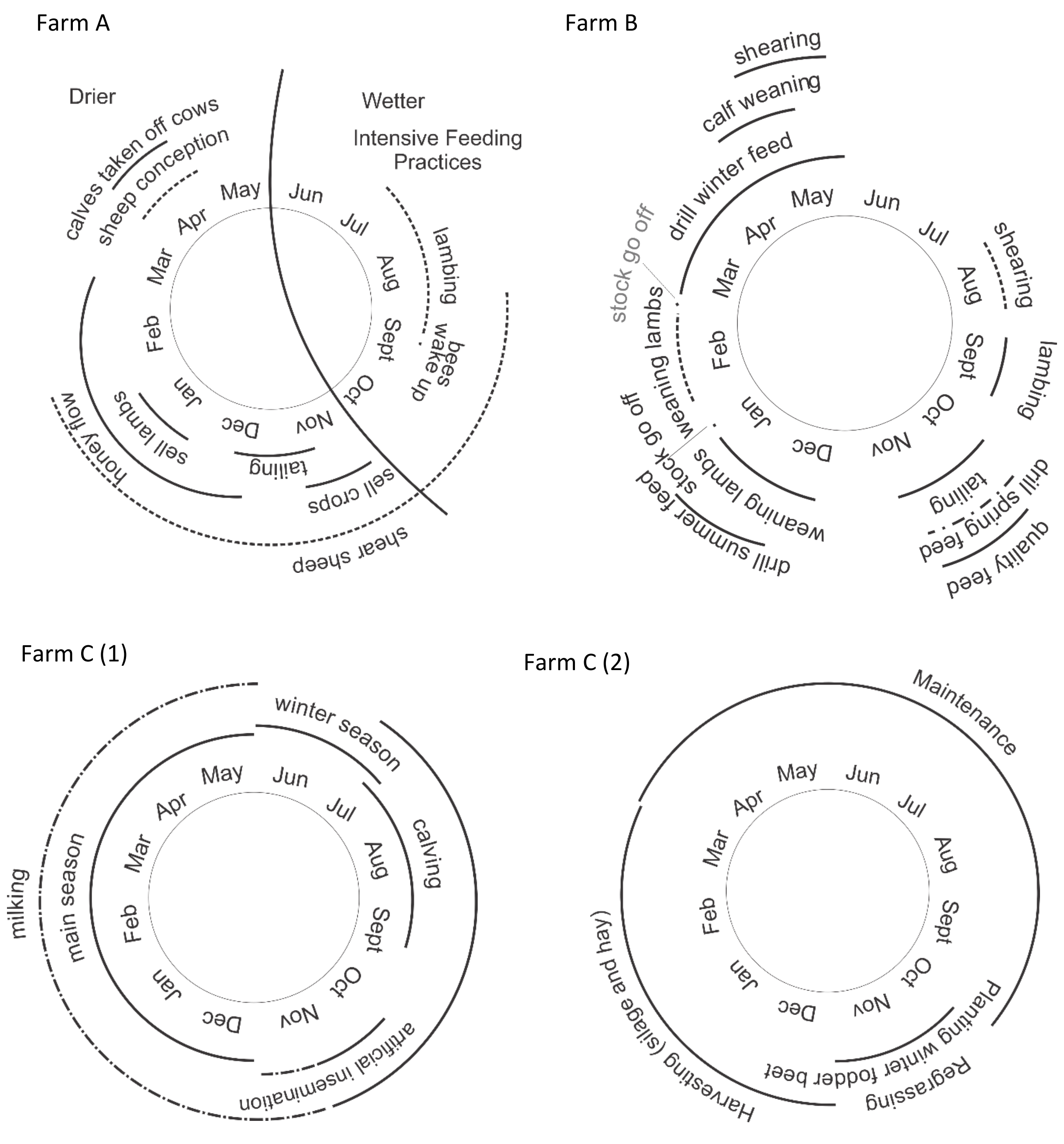



*Figure 6 The annual calendar of the farm contains all of the important farm jobs. These jobs are seasonal. Solid lines indicate the normal time for the noted task. If a job was skipped or shifted, they appear twice. Dashed or greyed lines indicate a job occurred, but at a different time than typical. Dash-n-dot lines indicates jobs that were skipped during 2017. Farm A marks the change between their wet and dry seasons. Farm C has two calendars, 1 is the milking platform and 2 is the runoff.*

Farms A and B, which are both sheep and beef farms, do not have identical annual calendars (Figure 6). Most of their major seasonal work occurs at roughly the same time. Their essential farm practices involving animal husbandry make up the bulk of the work. Several sheep-related farming activities were disrupted by earthquake and attendant coseismic hazards. The sheep have a much more seasonally-dependent schedule than the cattle. The woolsheds on both Farms A and B were damaged by the earthquake. The Farm A farmers initially borrowed a neighbour's woolshed to complete their tailing. The Farm B farmers were able to perform emergency repairs, but the woolshed repair delays moved their normal shearing time from May to August. The delay also caused changes to a number of smaller woolshed dependent activities, such as dipping for lice. The farmers resorted to using dry chemical instead of water-based ones. Dry chemicals have a longer withhold period to sell off animal meat. Thus, there was a knock-on effect of delayed wool and meat sales, which ultimately decreased the realised sale price. However, the majority of Farm B's activity offset was not earthquake-related but was shifted or skipped seasonal plantings and delayed lamb weaning due to unfavourable climate conditions. Farm A had two periods of sheep conception due to earthquake damage. Rams from a neighbouring farm entered Farm A through a damaged boundary fence. Coupled with their normal conception time in April, Farm A had a longer lambing period.

Farm C has two calendars (Figure 6) because the milking platform and the runoff operate almost independently of each other. The activities on the milking platform were disrupted by initial earthquake damage from November and persisted through the first half of 2017. Artificial Insemination (A.I.) was in progress at the time of the 2016 earthquakes. The Farm C farmers had to rely on other farmers to continue the process for them. As the milking shed needed to be completely rebuilt and the cows had been shipped off farm, the farm missed out on milking for seven months. None of the essential runoff activities were disrupted, even though there was damage to the water and fencing infrastructure.

Farm type is a factor in the level and type of disruption an earthquake has on a farm's calendar. Dairy farms are completely dependent on their dairy shed's ability to function because it is used daily for most of the year. The loss of the dairy shed halted the Farm C farmers' ability to operate on their milking platform. In contrast, the farmers of Farms A and B were able to work around their damaged woolsheds because they have seasonally variant use. Their farming practices were disrupted, but they were more easily able to adapt. Assistance from neighbours helped all of the farms complete vital farm tasks by lending them the use of their undamaged infrastructure and equipment.

### 3.2.3 Impact and Recovery Timelines

*Table 7 Key pre- and post-earthquake impact and recovery event timeline through January 2018.*

Impact and Recovery Key Events Timeline

| | Pre-2016 Earthquakes | $14^{th}$ Nov. 2016 | First week | Dec. 2016 | Jan. 2017 | Feb. 2017 | Mar. 2017 | Apr. 2017 | May 2017 | Jun. 2017 | Jul. 2017 | Oct. 2017 | Nov. 2017 | Dec. 2017 | Jan. 2018 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Farm A | Major infrastructure upgrade, Drought | Earthquake, evacuation home, loss of essential services and damage to essential infrastructure | Insurance agent visits farm | Power restored (early Dec.); Used neighbour's woolshed ($8^{th}$ Dec. 2016) | Water pump repaired ($14^{th}$ Jan.) | Landslide dam burst- lost water pump ($14^{th}$ Feb.); Water pump repaired ($15^{th}$ Feb.) | MPI uninsurables fund returned | Cyclone Cook and Cyclone Cook (Early April); Second landslide dam burst (Mid-April) | | | | | | Rawhiti cottage delivered | All insurance on-going |
| Farm B | Minor infrastructure upgrade, Drought | Earthquake, evacuation home, loss of essential services and damage to essential infrastructure, spoke to insurance | | Some water restored (early Dec.); Emergency stockyard repairs for weaning (mid-Dec.) | | | MPI uninsurables fund returned | Cyclone Cook and Cyclone Cook (Early April) | Water restored to woolshed; Moved into Rawhiti cottage | Stockyard repairs complete | | Moved into shed-house | Settled with insurance | | |
| Farm C | Drought | Earthquake, evacuation home, loss of essential services and damage to essential infrastructure, insurance visits, cows evacuated | Power restored ($17^{th}$ Nov.) | Staff let go (Dec.); Main off-farm road repaired (End of Dec.) | Damaged dairy shed removed | Damaged dairy shed removed | MPI uninsurables fund returned; Dairy shed construction begins | Cyclone Cook and Cyclone Cook (Early April) | | Re-staffed | Dairy shed completed and working ($28^{th}$ Jul.) | | | | Staff house insurance on-going |

Over the fourteen months covered by the interviews, each farm recovered from the impacts of the 14th November earthquake at varying rates (Table 7). The impacts of some events were experienced across each farm: the earthquake, large storm events and government interventions. The first six weeks following the November 2016 earthquake saw the most intense recovery for all three farms. The pathways for recovery diverged for each farm once emergency repairs were completed and individual long-term recovery priorities emerged.

Differing pre-earthquake decisions and practices on each farm influenced the initial earthquake's impacts. A three-year drought heavily impacted Farms A and B. The drought impact to Farm C was minimal because the farmers were able to continue to irrigate their fields. The Farm A and B farmers had decreased their stock to reduce the impact of the drought. Even so, the years of drought had caused significant economic losses. The farmers on both farms upgraded their water and fencing infrastructure during the drought. The Farm A farmers invested several thousand dollars upgrading their infrastructure. The Farm B farmers installed new water systems in part of the farm to manage the effects of drought.

Immediately following the earthquake, on all three farms buildings were evacuated. Family, staff and neighbours gathered together to evaluate the immediate post-earthquake situation. Farm C had the largest initial response to the earthquake. Its dairy shed's loss of functionality meant that all one thousand milking cows needed to be evacuated to other farms throughout North Canterbury. The dairy cow evacuation was facilitated by a team including the farmers' farm advisor and bank manager. Within 48 hours all the dairy cows had been settled onto other dairy farms in North Canterbury within dairy sheds similar to Farm C's. The task was made more difficult by damage to the main road, poor telecommunications and the fact that dairy cows are reluctant to use dairy sheds that are different from what they are used to. Thus, the receiving farms for the displaced herd were required to have rotary milking sheds that rotated in the same direction as the shed that had been damaged on Farm C.

After those first 48 hours, the priorities of the three farms became similar: restoring power, water and road access. Farm C, on river terraces near a major town, had these restored the quickest. The Farm A farmers stayed with family for the first few days due to the power and water access being immediately lost. The majority of their roads and tracks were damaged or destroyed. The woolshed was damaged and left without power, so the farm was unable to use it to complete planned shearing. Instead they were able to use their neighbours' woolshed. The job of walking the sheep to the neighbour's woolshed and shearing them took several days.

Following the earthquakes, the Farm B farmers immediately evacuated into a caravan and due to the damage to the house and risk posed by a slope that had a history of instability. They never moved back into their house. They lived in a campervan for several months before settling into a Rawhiti cottage in May. The Rawhiti cottage was sold to them at a discounted rate by MBIE. Farm B was also severely damaged across the farm. Surface ruptures across the farm damaged paddocks and the power supply, and killed many sheep and some cattle both during the initial earthquake and in the following weeks and months. The farmers began construction on a shed-house that they were able to move into in October.

Farm C has its own wells and with the use of a generator its time without water was short. Power was restored within a couple of days. In the meantime, the farmers were able to use their generator to power a few houses and the wells. Despite the swift restoration of essential services (*e.g.*, the main road was repaired within six weeks), Farm C's dairy shed loss meant that the farmers missed out on most of the milking season and had to let go all but one of their staff. The farmers were able to take advantage of MBIE fund to pay their employees during the interim between losing the milking shed and letting them go. They also applied to and received money from MPI's uninsurable fund to cover their fencing damage.

Unlike Farms A and B, Farm C did not experience on-going hazard events stemming from this earthquake. Farm A's water access, fences and flood gates were damaged several times by reactivated landslides and landslide dams bursting. Farm B's homestead was at imminent risk from a reactivated landslide. Both continue to have landsliding across their properties. All three farms have seen changes to their drainage patterns.

The speed with which insurance applications were settled also varied between the farms. Farm B's insurance was not settled until November 2017. The insurance resolution delay kept the woolshed unusable until August, which led to a delay in shearing sheep and sales. Without water the farmer had to resort to using dry solutions to dip their sheep. The use of dry solution chemicals decreased their meat prices by delaying the time they could send the meat to market. Any delay in selling decreases the price the farmer can get. Farm C's insurance was very quick to assist with the dairy shed rebuild. As of January 2018, the settlements for the damaged staff houses were still on-going, but despite the farm's smaller-than-optimal staffing option, the restoration of staff accommodation buildings is not a priority. Farm A which had only minor write-off structures settled and as of January 2018 had not settled any of its major insurance claims.

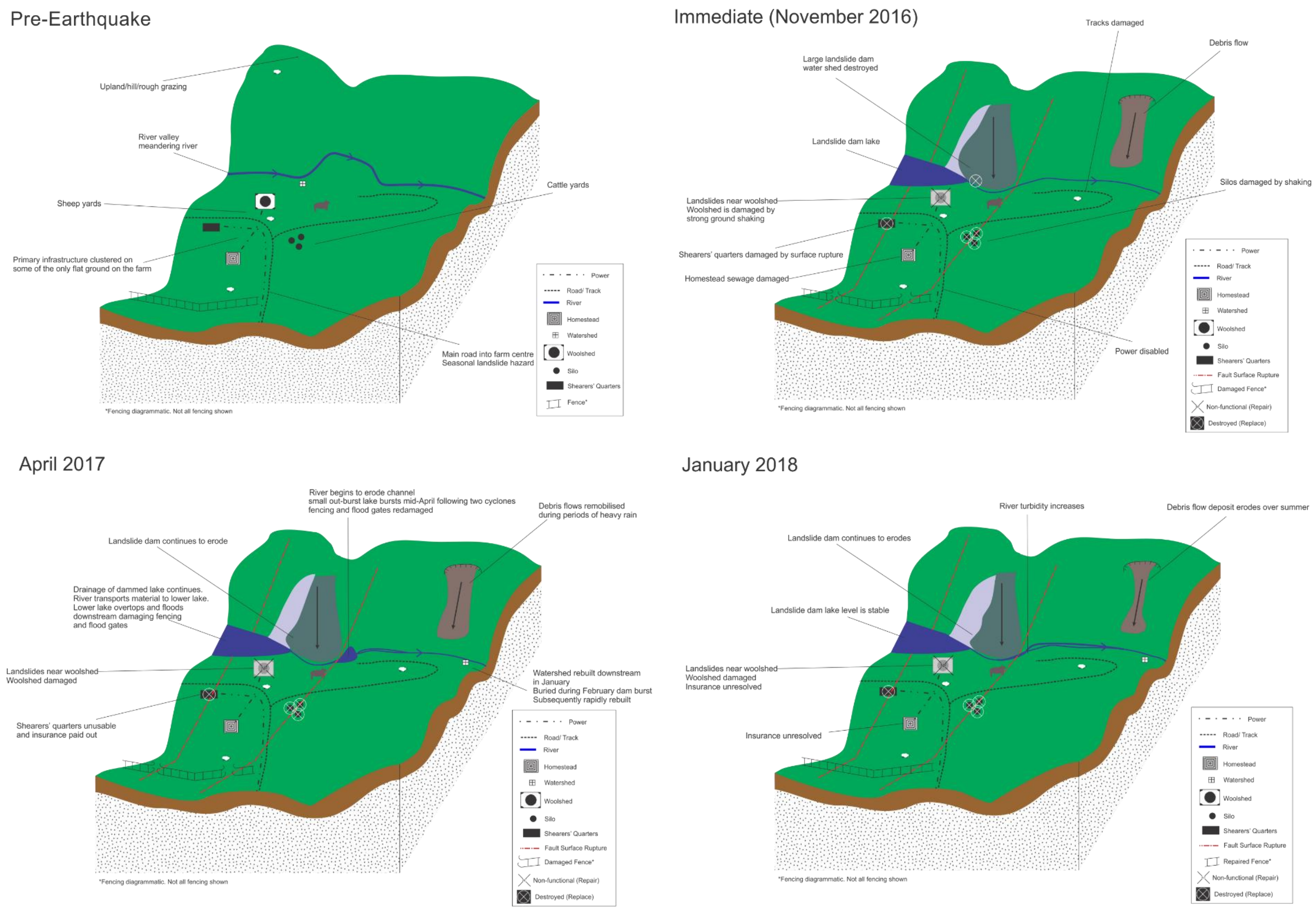



*Figure 7 Block models demonstrating the major geological, infrastructure and service changes pre-, immediately post- and over fourteen months of recovery on Farm A.*

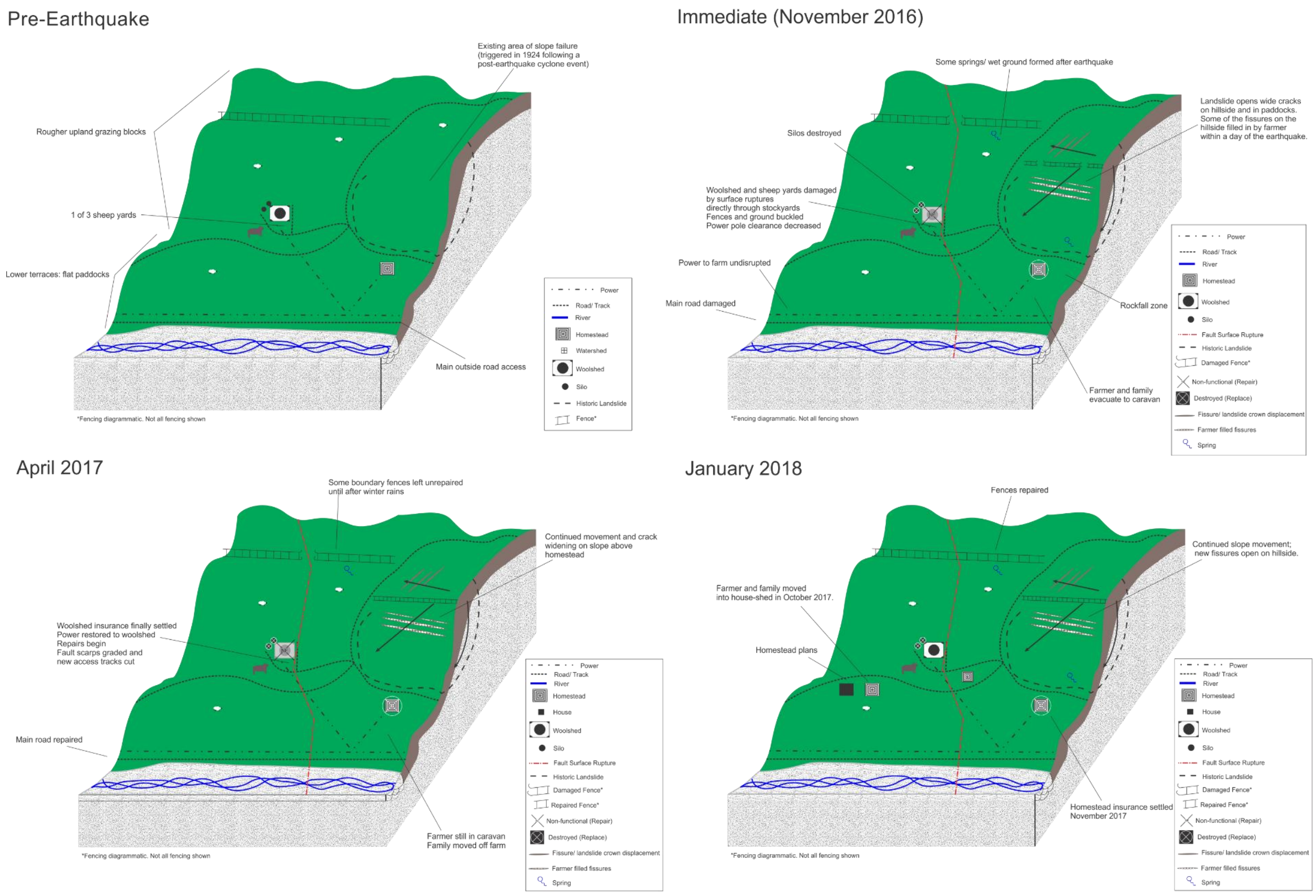



*Figure 8 Block models demonstrating the major geological, infrastructure and service changes pre-, immediately post- and over fourteen months of recovery on Farm B.*

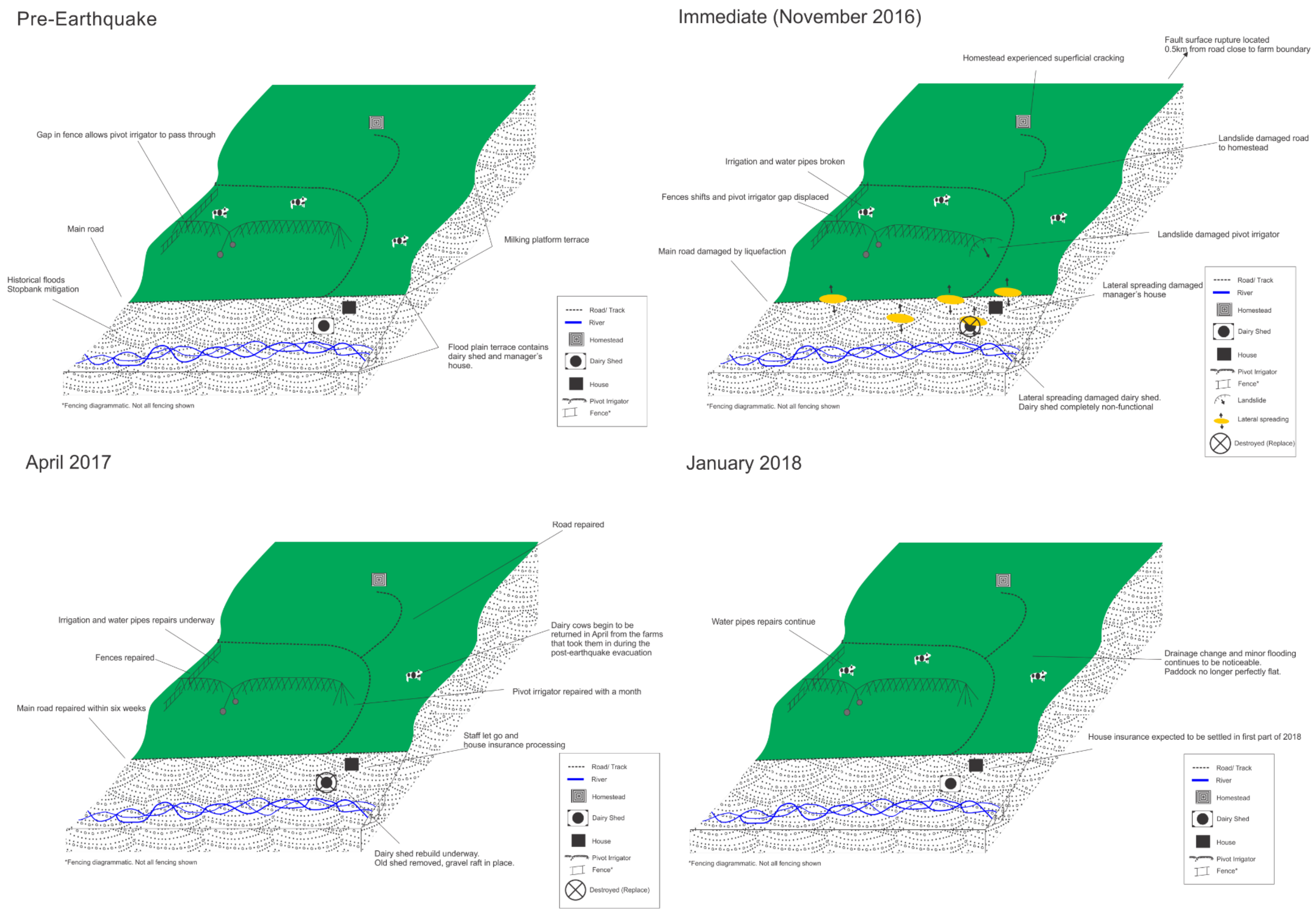



*Figure 9 Block models demonstrating the major geological, infrastructure and service changes pre-, immediately post- and over fourteen months of recovery on Farm C.*

#### *3.2.3.1 Key Events Timeline Summary*

The condition of the farms at the time of the earthquake influenced how they were impacted geologically and economically. The Farm A and B farmers had to deal with capital and livestock death issues steaming from the droughts and recent infrastructure upgrades. Both farms also experienced landslide reactivation. During the initial phrases of recovery, all of the farms priorities were roughly the same: life (of humans and livestock); lifelines, power and water restoration; and then infrastructure repair. Farms A and B experienced on-going or cascading hazards while Farm C did not. This was due to the topographic and geological variations between the farms. The farmers repaired their infrastructure and essential services at various speeds based on insurance resolution timing, capital availability and priority.

## 3.3 Case Studies Summary

The case studies in this thesis are three Hurunui District farms significantly impacted by the Kaikōura/Hurunui Earthquake Sequence (Figure 7, Figure 8 Figure 9). They are an extensive hill country sheep and beef farm (Farm A), a steep hill sheep and beef farm (Farm B) and a flat river terrace dairy farm (Farm C). The farm characteristics influenced initial and on-going impacts. The differing topography on each farm varied the occurrence of on-going geohazards. Farmer hazard experience increased resiliency across all three farms, particularly during long-term climate events. Farmers applied lessons from these events to develop infrastructure and service backups that increased resiliency. Initial recovery is rapid emergency repairs with similar priorities (life, power and water) for all the farms. After the initial recovery slows down, the speed and priorities of long-term recovery vary for each farm.

# Chapter 4 Analysis

## 4.1 Introduction

This chapter explores five themes encompassing the key issues and aspects of farm impacts and recovery drawn from the case study interviews: Pre-existing conditions, Earthquake Impacts on Physical Environment, Essential Assets, Human Factors, and Economic Factors. The themes were developed from analysis of the case study interviews and previous literature *(e.g., Craig et al. 2016a; Farmar-Bowers & Lane 2009; Whitman et al. 2013)*. These themes interact with the impact and recovery timeline of each farm. The factors identified through the themes contribute to the vulnerability, exposure and resilience of the farms and farmers before the earthquakes; evolve over the course of the earthquake and recovery timeline; and future plans, goals and changes. Each theme section explains how that particular theme relates to farm impact and recovery in detail with key quotes and anecdotes. Section 4.2-4.6 contain the analysis and breakdown of the five themes. Section 4.7 discusses the impact and recovery timeline of the case study farms. Section 4.8 details the future plans and approaches of the case study farms. Section 4.9 summarises the key findings and recommendations from each theme and the timelines.

## 4.2 Pre-existing Conditions

Pre-existing conditions refer to major physical factors that influence the vulnerability, expose and preparedness of the farm pre-earthquake. Three major factors are: regional climate trends, farm geography and geology, and farmer experience. Pre-existing conditions may magnify or reduce the effects of the earthquake and related hazards, and influence recovery.

### 4.2.1 Climate

The influence of climate largely outside the scope of the farmer’s control. The regional effect of climate trends can limit resources. However, major climate issues (*e.g.* droughts, cyclones) may trigger an influx of resources into the region through government or NGO aid. Seasonal weather and farm priority changes also contribute to farm vulnerability. The time of year can adjust farm characteristics and resilience. Climate effects available resources and geohazard probabilities.

In 2015, a drought was declared in North Canterbury that continued through 2016 (Environment Canterbury 2016). Farmers make a variety of management and business decisions in order to survive the drought. The drought also effects the soil properties; reduced soil moisture increases effective stress and generally reduces the probability of a slope to undergo landsliding. Farms A and B were significantly affected by the drought. One farmer commented the following on their on-going dry weather:

> *"…We were as dry as we had ever been in December [2017], in the last four years, we were just dry. Obviously, the whole country is dry. We've had some unusual rain and that's sort of relieved the pressure. The big things are: you've got less animals, prices are higher this year and we aren't able to capitalise on those prices. So, costs you when you sell those animals because you sell them cheaply. Like this year we sold some ewes, we probably averaged 140 dollars. At the high of the drought, I think we sold them for forty dollars. Supply and demand now. So, you're at the bottleneck of the drought now because people are starting to rebuild because the optimism restores itself. Grass comes and people have to restock, they sold low and they have to buy high."*

Farm A's business decisions during the drought lessened the financial blow of the earthquake in an unexpected way. A farmer commented that their drought strategy of stock reduction also reduced earthquake impact:

> *"Three years of below average rain is the most recent activity. That has had a cascading effect because we had less animals when the earthquake hit. We were probably down 25 to 30 percent of our normal carrying capacity. That allowed us to open the gates and let the animals find a drink as opposed to a more complex management system were you're trying to maximise grass grown and output. So, from a livestock perspective the pressure was greatly reduced, which allowed us to focus on fixing stuff. And then our income doesn't seem to have been compromised too much. So, that was really pleasing to maintain the cash flow of the business. It would've been different if my flats had been covered in barley and I had to harvest them with a harvester. That would've been major."*

Climate and weather influences earthquake-related geohazard probability as well. The soil type and moisture content influences the degree of landsliding. The severity of on-going hazards varies in part due to the seasonal changes following the earthquake. The time of year that the earthquake occurs influences the severity of the coseismic hazards. On the seasonal changes to Farm A, a farmer commented:

> *"Generally, you could probably divide us through there and that would be wetter, that would be drier. That's just how this farm operates and with our soils it's like ice. When you get clay tires and clay ground you just slide. And obviously that blue subsoil stuff is really friable. That's where we tend to get the slips. We are a pretty simple system."*

This farmer predicted that the relatively dry climate and time of year saved Farm A from more severe damage:

> *"I reckon that if we'd had got that earthquake like now [August 2017] or if we'd had it in a really wet summer and the ground was water logged anyway the topsoil and the clay- Cause we're so clay based up here and parpari clay and stuff. You've got this water that lubricated the topsoil and the clay 'cause we get slip up here anyway. Quite big ones. It just gets waterlogged and it falls off. If we'd have got that earthquake at a different time of the year or when rain levels had been at averages, or slightly above, I think the scope of damage would have been horrific."*

The farmer's preparedness and ability to react changes depending on the time of year as well. Farm A believes that the earthquake occurred at the best possible time for their farm. It did not to interrupt essential tasks and their equipment was readily available to begin repairs. The farmer commented:

> *"The likes of my tractor would be engaged everyday feeding out hay and getting me to and fro but because all that had been done, in November my tractor was free and I could use it to help fix things."*

### 4.2.2 Geography and Geology

The geographical and geological characteristics of the farm influence its vulnerability to geohazards and resilience. These environmental aspects of each farm control the magnitude of earthquake experience, the initial coseismic hazards and on-going hazards. See Section 3.2.1.1 for an overview of each farm's physical characteristics.

The key aspects of a farm's physical environment that influence geohazard occurrence and severity are: topography, and soil and bedrock characteristics. Topography influences the type and magnitude of earthquake triggered hazards. Farms A and B have steep hills and experienced a greater degree of landsliding than Farm C, which is low relief. Farm C, on a river terrace, had more liquefaction than the other two farms because it has the most saturated sandy soil.

The Farm A farmers credits their geographical isolation with aiding the development of their resilient attitude and essential service back-ups (Section 4.4.2 ). The three farms are aware of their relative isolation due to being in rural rather than urban environments. They have built forms of resilience (*e.g.,* generators, digital-based communication systems) into their farms in response to this awareness.

### 4.2.3 Experience

Farmer experience is the most important pre-earthquake resilience factor. It shapes pre-earthquake and recovery decisions. Experience refers to the knowledge farmers have with regards to how to run and operate their farms. According to Folke *et al.* (2003), "*combining different types of knowledge for learning*" is one of the four factors that influence resilience. Farmar-Bowers & Lane (2009) described different types of knowledge, such as personal strength and outside influences, as part of the influencers of farm decision-systems. The experiences highlighted in the presented case studies fall into the categories of lifetime experience, occupational experience and spatial experience (Table 8). Lifetime experience is closely connected to a farmer's age. Occupational experience is a farmer's knowledge of farming. This knowledge may have been gained from other farmers or when working on other farms, as well as their own. Spatial experience is a farmer's knowledge of their particular farm and land. Hazard/disaster experience is context specific and is divided amongst the experience categories. Community memory and knowledge has been related to reduced disaster-related deaths (Berkes 2007). Berkes (2007) also found that diversification of knowledge sources increases resilience, whether it is multiple forms of experience or the adding of local case studies to the area of global science.

*Table 8 Farmer experience in three categories: lifetime, occupational and spatial. Lifetime experience refers to general life knowledge (e.g. patience and coping mechanisms). Occupational experience refers to experience with the specific type of farming the farmer is currently active in (dairy or sheep and beef). Spatial experience refers to experience with their particular farm/property. Low (>10 years), Medium (10-20 years), High (<20 years). Farm A are young farmers who have been working in sheep and beef on their farm for just over ten years, but the farm has been in the family for almost 100. Farm B are also young farmers who have been working in sheep and beef on their farm for just over ten years and are new to their land. Farm C has a lifetime of experience on their farm, but has only recently switched to dairy.*

Farmer Experience

| | Lifetime | Occupational | Spatial |
|---|---|---|---|
| Farm A | Medium | Medium | High |
| Farm B | Medium | Medium | Low |
| Farm C | High | Low | High |

#### *4.2.3.1 Lifetime Experience*

Lifetime experience is gained over time and can also be referred to as common wisdom. This experience is not farming specific but can be applied to farming. Lifetime lessons teach patience, resilience and coping mechanisms for difficult long-term situations.

Farm C has the oldest of the farmers and consequently the largest pool of lifetime experience. They credit their age and experience with giving them stress reducing patience and perspective. One of the farmers commented:

> *"…being a bit older and a bit more experienced, we are reasonably resourceful and think that's very important…Younger people expect more than we do. And I think that's helped me and us get through that, hasn't it? Puts it in perspective, it's only an earthquake. We're still here. We can go down the pub and have a beer on Friday. We aren't in Syria and getting bombed every night. So, when you put it down, it's a big event for us and I don't want to go through another one, but it's not the end."*

Living through adverse periods is an accelerated way of gaining this type of experience and it can shape perspective and coping mechanisms. Farms A and B survived through a severe drought before the earthquake. For the Farm A farmers, this left them with a determined commitment:

*"After three years of drought, you're either into it for the long haul or not. And you just hope that you're in it long enough to pay the money back."*

The drought made the Farm A farmers' approach to farming more conservative. This approach may pay off if they avoid losing money in risky financial endeavours but may also limit their flexibility and mean they miss out on potentially lucrative ventures. One farmer says their mentality might go against the common diversify advice, but not everyone would agree. They described their conservative approach to drought survival as a more traditional approach to risk management:

*"Three years of drought is, obviously, a lot time. It's almost like doing a degree in how to survive droughts. You tend to come out the other side of it as quite conservative. I was always told that if you could afford to diversify not to. That's probably the opposite of what a lot of people say. Don't put all your eggs in one basket. But, an old guy said, 'If you've only got one ball to juggle, you probably won't drop it.' There's all that sort of risk management."*

Whether from gained age or living through difficult times like drought, lifetime experience can benefit a farmer's mental and emotional response to a disaster. This experience is transmitted through the advice and stories of other farmers who have been in similar situations. Strong farming community and family networks allow farmers to use each other's experience.

#### *4.2.3.2 Occupational Experience*

Occupational experience refers to a farmer's experience with their specific type of farming. Dairy farms and sheep and beef farms do not operate the same, so while there is some experience overlap, experience of one does not equate to experience with the other. Farm C had been a sheep farm for decades but had only been a dairy farm for nine years. Therefore its farmers have lower occupational experience than the other two sets of farmers.

As with the Farm A farmers, the Farm B farmers have had the experience of farming through a drought. They found that they had learned quick adaptability. This ability came from knowing their type of farming well enough to improvise plans. One farmer said:

*"…we'd learnt from the previous two years that you make some quick decisions and- So, we were back in drought mode and we were starting to sell some capital stock and looking at grazing out. And then, like in the blink of an eye, it just changed. We were really lucky. Before we'd had to put some of those plans too deeply in place, we went back to sort of a normal autumn."*

This flexibility was also applied to manage the variable soil conditions in the year following the earthquake that were climate related. There were periods when the soil was hard and dry and other when it was water logged.

A Farm A farmer has also learned a day-to-day adaptive managing style. The farmer described this flexible style:

> *"Yeah, I probably farm in my fingertips. You know, I don't go to bed the night before with a list. Again, because I'm only dealing with myself. I mean today, this morning, I spent half an hour with the fencing contractors. Last night I did today's work, so I could have a sit down with you guys. And this afternoon I'll deliver some materials to the contractors. And then I'll go and feed the animals so I can have tomorrow off. So, I basically only get one day off in a weekend if I'm lucky. I've increased my employment. I've employed a guy just to do a lot of the stuff that I was doing day to day and that frees me up to deal with the contractors."*

Sometimes farming experience is not helpful. A Farm A farmer commented that water pipe wisdom did not apply in earthquake situations:

> *"I love all those things. 'You always bury your water pipe as deep are you can.' All the pipes on top of the surface are fine. It's all the stuff we buried that's buggered. I don't' mind that because it just tells me that you can't win sometimes and that's ok."*

Occupational experience is knowing what does and does not work for a particular type of farming. It shapes the management style the farmer uses. When an event is far outside a farmer's experience and the experiences of those they've learned from, then impacts can be worsened or recovery can be negatively affected.

#### *4.2.3.3 Spatial Experience*

Spatial experience is a farmer's knowledge about their particular farmland. It might come from years of working that land or from previous owners. An earthquake reshapes land in ways that can make spatial experience useless. At the same time having spatial experience aids in knowing how an earthquake might trigger a hazard cascade. Not all spatial experience is advantageous.

##### 4.2.3.3.1 Experience Source

Spatial experience can come from living and working on a farm or from the records of previous owners. Farm A and C have been in the current farmers' families for decades. The Farm B farmers are relatively new to their land, but they have access to decades of the records from previous owners.

The Farm A farmers credits the amount of time they have spent farming and in particular farming their farm for limiting the stress and panic they experienced. Their recognition of their isolated location means that they have taken steps to become more self-sufficient (Section 4.4.2.4 ). One farmer commented the following about their confidence:

> *"But I had twelve years of being in control of this farm. If this had happened in my first one or two years, I think my response might have been a lot more maybe emotional even. Just stressful. I just got a lot more experience with the property and knowledge about what's going on and what I can handle. So, from a personal perspective, I think that helped."*

The Farm A farmers have nearly a century of family history and experience with their land. They said:

> *"But after 97 years, we seem to know what works. And it's generally a sheep dominated system."*

The Farm B farmers do not have the years of family experience that the Farm A and C farmers have. Therefore, there were plenty of systems whose locations they were unsure of because they did not personally put them in. A farmer mentioned how this impacted emergency repairs:

> *"Lucky, we had been here for quite a lot time before the earthquake and I had a rough idea where all the pipe lines were. I knew where some of them were because we had fixed them or put them in, but we were three weeks with a digger after the earthquake."*

Despite the disadvantage of not having lived on Farm B for their whole life, these farmers were still able to tap into farm-specific knowledge. In the case of Farm B, previous owners have left detailed weather records. So, they have the benefit of one hundred years of rainfall records for their property. These have allowed them to be aware of and prepare for climate trends. The farmer described these records:

> *"When we've gone through a dry spell and we have averages. We have rainfall data from the neighbour back to 1907 have been recorded and there's even a MetService weather station up there. So, the last sixty or so years, it's been recorded not just farmer's readings, but it's been officially recorded. That when you get averages and you can see from the last hundred and ten years, whatever it was, we did get these really dry spells, but it'll make up for it. You'll get a really wet spell. And that's exactly what happened last winter. "*

On Farm C, one farmer had had the benefit of more than one lifetime of farming experience on the property, growing up these to take over from his father. Of their on-farm experience, the farmers said:

> *Farmer C1: "I think it's just experience. We know what this farm does well. And we employ staff and they all come in with their own ideas, but we're quite adamant now we know what this farm does and we'll stick to that rather than chopping with different people's views."*
>
> *Farmer C2: "Use as much technologies as we can and things like that, but the basic systems we stick mighty close to them."*

#### 4.2.3.3.2 Farm Hazard Experience

Earthquakes can change the landscape dramatically. Normal hazard zones can be deactivated and new hazards can form. This challenges how well a farmer can plan for cascading hazards because some of their spatial knowledge may have become obsolete. This was the experience on Farm A when the land that years of experience had taught them was slip-prone was not the land to slip during the earthquake. These farmers now perceive their land to be more prone to landsliding and shaking damage than before due to the earthquake. A Farm A farmer described how this unease influences their understanding of risk:

> *"But then you see your flat paddocks up the flats dropped off and then you've got these fault ruptures and they are forming pies, which to me is a bit freaky. And then just the loosening. I just think everything has just been loosened. Even though it might not move now, it's probably going to move at some stage and even a smaller event in the future doesn't need to work as much to move things. The big work's been done. Everything's been separated. You might get a 5 or a 6 in 20…thousand years' time. Gets back to that classification of faults whether it's a 400-year fault or the probability of things. I just feel as though in the future, we might be on the outside of big event, but because we are so shaken and loosened here, we may experience more here because of that. That would be my logic.*
>
> *That's where I am really concerned personally about the woolshed site. Is that it's more the cascading effect of another event now."*

Floods, unlike earthquake, are easier to predict and mitigate. Farm C was impacted by twice yearly and ten-year floods. The local community flood mitigation scheme has successfully reduced the frequency of these events.

### 4.2.4 Pre-existing Conditions Summary

Many of the pre-existing conditions fall outside the farmer's and even outside forces' realms of influence (*e.g.,* climate). Knowing what the pre-existing conditions are (*i.e.* the geohazard influencing environmental characteristics) and vulnerability of the farm to earthquakes ahead of time allows for better preparedness. Experience does not change the impact of an earthquake, but it can influence both how a farmer reacts, and rates of post-earthquake recovery. The different types of experience are acquired in different temporal and spatial senses, but they combine to shape a farmer's response. The most organic way to gain experience is with the passage of time. However, these experiences can be learned from other people. Spatial specific experience can be gained from the farm's previous farmers through records, journals or family conversations. Occupational experience can be gained from field experts and training courses. Lifetime experience can be transferred through conversations with family and the community. Experience off all types and pre-existing condition awareness leads to better recovery decisions.

## 4.3 Physical Environment

When the earthquakes struck they shook the land and infrastructure of the farms. Numerous coseismic hazards were triggered. Liquefaction and lateral spreading occurred in the saturated, sandy river sediments. The ground warped and deformed. Over 10,000 landslides formed, many of which slid into rivers to form landslide dams (Massey *et al.* 2018). Some of these landslide dams burst multiple times over the course of the following few months. A few have since formed permanent lakes. Rockfall occurred on many of the areas hills and cliffs. The farms directly on the activated fault lines had surface ruptures of up to 9m vertical and 11m horizontal (Litchfield *et al.* 2018) . The occurrence of these hazards was not just limited to the time of the earthquake. Over the course of the year, several of these hazards reactivated, further damaging infrastructure and undoing repair work. These cascading hazards became a distinct obstacle in the farm planning efforts moving forward.

### 4.3.1 Liquefaction and Lateral Spreading

Liquefaction and lateral spreading was restricted to the saturated, near river sediments. Liquefaction was not as widespread an issue on the South Island as it was during the CES (Stringer *et al.* 2017). Most damage was on river terrace farms like Farm C (Figure 10).

*Figure 10 The impacts of lateral spreading on bridge abutments and road near Waiau. Photographs by C. Fenton (18 November 2016).*

Farm C's dairy shed was within the flood plain of a wide river. Lateral spreading beneath it cracked the foundation and made the shed non-functional. The farmers reported boulders had been jettisoned out of the river sediments as well. Several of their paddocks were damaged so badly that they needed to be reflattened. A farmer said:

> *"We got more so down on the dairy shed was, on the flat down there. It's boulders underneath, so we got boulder-faction. Little heaps of boulders came up, so we had to heavy roll the whole place."*

Farm C's main off-farm road was damaged by liquefaction and was impassable for several weeks.

### 4.3.2 Landslides

Landslides formed across the hilly and mountainous landscape. They broke fences, buried livestock and slid into rivers to create dams.

*Figure 11 Landsliding in the Hurunui District. Note the fence damage in the middle of the image. Photograph by C. Fenton (13 December 2016).*

Farm C, on flat river terraces, was the least affected by landslides. There was minor landsliding on the edge of its terraces that damaged the on-farm roads and a pivot irrigator.

Several landslides formed on Farm B. A large landslide above the homestead reactivated. In response, the farmers evacuated their homestead and spent most of the year following the earthquake setting up a permanent house on another part of the property.

Most of Farm A's landslides damaged fences and paddocks. Part of its flat land dropped as landslides formed. The farmers have fenced off sections of land against stock use due to the increased risk. The woolshed is immediately adjacent to an area of slope failure and surface rupture.

The largest landslide on Farm A formed a landslide dam on the main river creating a lake that persists to date.

### 4.3.3 Landslide dams

Landslide dams form when landslides block rivers. They frequently form lakes. The main risk from landslide dams is that they will eventually fail by overtopping breach. When this occurs, the immediate downstream area will flood and can possibly be subject to significant scour and/or sedimentation. Larger landslide dams may burst several times or stabilise into permanent lakes (Tacconi Stefanelli *et al.* 2016).

*Figure 12 Landslide dam and impounded lake on the Stanton River, Hurunui District. Photograph by C. Fenton (13 December 2016).*

Only Farm A was directly impacted by a landslide dam. The farmers heard the large landslide forming within the first two minutes of the earthquake. Farm A's pump shed was buried by the initial landslide. The pump and generator was restored downstream by mid-January. A month later, the lake overtopped the landslide dam. The downstream area was flooded and the new pump and generator were buried. The fences and flood gates were damaged during every overtopping event. One farmer described the extent of the damage:

> *"So, on the 15th of February when the dam overflowed. We lost our pump and generator that was pumping water out of the river. So, that sort of left it in a precarious position….and then the underground pipe. We towed an underground pipe in, which wasn't towed in deep enough, even though we had a 30-ton digger. That was washed out and damaged when the flood water came through. So, we've actually lost our spring 'cause that pipes been damaged."*

The breaching of the landslide dam lake also formed a second smaller lake downstream. In the aftermath of a Cyclones Cook and Debbie in April, this smaller lake also breached. On Farm A, this event caused significant additional damage. One farmer described the impact:

*"[When Lake Ray burst on the 16th/17th April,] I got a whole new level of damage to my fences and flood gates. And luckily, we did get some insurance because we're covered for flooding, but not earthquake. So, we got some money out of the insurance company for that."*

The surface of Farm A's earthquake-formed lake has changed elevation since formation, but it appears to have stabilised by January 2018.

### 4.3.4 Rockfall

In comparison to landsliding, rockfall was only a minor issue on the hilly farms. A Farm B farmer is the only one to have specifically mentioned it. They chose to cancel an event due to the risk.

*Figure 13 Rockfall onto and partially blocking a farm access road in Hurunui District. Photograph by C. Fenton (16 November 2016).*

### 4.3.5 Surface Ruptures

Besides landslides, surface fault ruptures were the most dramatic geological hazards. The surface ruptures offset fences, paddocks and buildings. On the farms, at least one building was destroyed by surface ruptures. Several others suffered significant damage form fault-related ground displacement (Van Dissen *et al.* 2018).

Farm A's shearers' quarters was offset by a surface rupture, which rendered it uninhabitable. The same surface rupture was proximal to their woolshed.

Pipes and powerlines throughout the farms were offset and broken by the surface ruptures. Surface ruptures developed through Farm B's woolshed stockyard. Surface rupture raised the land by 1.5m beneath the last power pole before the woolshed. The decreased clearance meant that the power had to be disconnected until a new line could be installed.

*Figure 14 Surface ruptures damaging fences and gates. Differential ground displacement damages gates and lifts fence posts and waratahs out of the ground. Photographs by C. Fenton (11 January 2017 and 27 January 2017).*

### 4.3.6 Ground Deformation

The faults deformed and warped the ground on all of the farms. In response various physical assets of the farms moved or were damaged. Fences and pipes, as long connected units, were the most prone to damage. Land levels changed as a result of fault displacement that altered drainage patterns.

*Figure 15 Flooding in paddock and tilted powerlines due to liquefaction-induced ground deformation along the Waiau River floodplain. Photography by C. Fenton (28 November 2016).*

The main road to Farm A was further damaged during the winter rains. After three years of drought rainfall was occurring at normal winter levels, which combined with new drainage paths caused this additional damage.

On Farm C changes to groundwater have been the longest continuing hazard. As one of the farmers commented in October 2017:

> *"I must say, out of that day, I'm still suffering ground damage. Where the quake has split the ground, there is a lot of water lying around where normally, I would be able to work those paddocks. I haven't been yet. So, I think down the road there the water table seems higher at this stage. So, that's affecting us a wee bit."*

### 4.3.7 Geological Cascading Hazards

Cascading hazards are a series of interlinked hazards that form over time and space (Pescaroli & Alexander 2016). Hazards can be triggered or reactivated by other geological hazards (*e.g.*, earthquakes, landslides), weather and human activity. The 2017 autumn cyclones and winter rains reactivated many landslides throughout the region. The landslide that reactivated behind the homestead on Farm B is an example of a long time period of hazard activation. The landslide was first recorded to have moved during the 1922 Motunau earthquake and after a cyclone the following year. Farm A was also subject to cascading geological hazards. Their landslide dam burst several times. It created another smaller landslide dam lake, flooded the downstream area multiple times and reshaped the river's course. Multiple hazards can combine over time to do further damage. For example, the return to normal winter rain levels after the reduced precipitation of the drought and earthquake changed drainage patterns that then damaged Farm A's road. Cascading hazards must be taken into account for all future planning. As a Farm A farmer put it:

> *"Part of your mind set just not realising the next cascading thing. I think now I'm more aware of the next thing coming."*

### 4.3.8 Physical Impacts Summary

The initial and cascading geological hazards associated with the earthquakes both damage the infrastructure and essential services, and endanger lives on the farms. The internal and external resources of the farms are all employed to mitigate these hazards and maintain the function of the farm into the future.

## 4.4 Essential Assets

The essential assets of a farm are its infrastructure, services and livestock. The infrastructure encompasses the buildings and other structures on the farms. The essential services (*e.g.,* water) are either delivered from off-farm or sourced on-farm. All three farms are mixed arable-livestock. Their livestock are their key economic resources. The earthquake and coseismic hazards directly impacted the farms' essential assets.

### 4.4.1 Essential Infrastructure

The first concrete impact of the earthquakes is on farm infrastructure. Each farm has at least one primary economic infrastructure building (woolshed, dairy shed), a homestead and a collection of other infrastructure (*e.g.,* staff houses, water tanks, sheds, fence, tracks). Damage or destruction of the primary economic infrastructure is an immediate concern to a farm's stability. It may also be a threat to livestock health and safety. The impacts of a damaged or unsafe homestead can influence a farmer's ability to mentally recover. Damage to or destruction of infrastructure such as water tanks, sheds, fencing and tracks also has more than economic impact. It can impact employment capacities, essential service access, and livestock health and safety.

#### *4.4.1.1 Primary Economic Infrastructure*

Each of the three case study farms has only one currently operational primary economic infrastructure unit. Farms A and B both have woolsheds with surrounding stockyards. Farm C has a dairy shed, which includes milk storage tanks, and is also surrounded by stockyards. The earthquakes severely impacted the building complexes on all three farms.

Woolsheds are used 2 or 3 times a year, which means that they are much lower occupancy buildings than dairy sheds, which are used daily for around 10 months of the year. However, when the woolsheds are being used they are high occupancy buildings full of contract workers and sheep.

Farm A's woolshed is situated on the small section of flat land on which most of its primary infrastructure is located. It is near the edge of a steep river valley. It was damaged by earthquake shaking and is in close proximity to surface rupture and landslides activated by the earthquakes. As of January 2018, the woolshed is still awaiting repair and declared unusable because the farmers have yet to reach an acceptable settlement for the shed. The farmers' and insurers' disagreement stems from the multiple hazard risks (surface rupture and landslides), building code classifications and wording of the insurance.

Farm B's woolshed is also situated on their small section of flat land. Surface ruptures went right through the stockyards outside the woolshed and uplifted the ground beneath its powerlines. The power was disabled until ground repairs could be made. The immediate concern was the completion of tailing. The farmer did emergency pre-Christmas repairs to the stockyards in order to finish tailing. Like Farm A, Farm B's woolshed repair was delayed due to postponed insurance resolution. Pre-Christmas discussions with contractors and insurance indicated that they would have a functioning woolshed by February, but after Christmas, this estimate changed to July. These delays disrupted normal animal husbandry practices and negatively impacted the year's wool prices.

Farm C's dairy shed is located on a river terrace several hundred metres from a river. The building complex includes stockyards, silos and milk storage tanks. The earthquakes caused the lateral spreading of the loose, saturated river sediments beneath the dairy shed. As morning approached on the day of the earthquake, the farmers realised that their milking shed was not going to be functional. The bulk of their initial energy was thrown into relocating their cows to various farms in North Canterbury that could milk them. Farm C's insurance company played a large part in the rapid rebuilding of the dairy shed, which operational on July 28$^{th}$. The process was also sped by the farmers spending the month of January researching dairy shed and builders, and a neighbour buying their old dairy platform.

The damage and permanent disabling of primary infrastructure had significant impacts on the ability of the relevant farm to function and complete essential animal husbandry tasks. The loss of primary economic infrastructure also diminishes the financial return a farmer can receive if they chose to sell their farm in the aftermath of an earthquake. A sheep farm without a woolshed is just a piece of land.

#### *4.4.1.2 Homestead*

A farm without a homestead is not a home. All three sets of farmers live on their farms. None of the homesteads was significantly damaged as a direct result of the earthquakes, but one was declared uninhabitable due to imminent risk from a reactivated landslide. There is a significant mental/emotional impact during the recovery process. Damage and insurance delays with regards to homestead repair influence the ease at which farmers can make recovery decisions about the rest of their farm.

*Figure 16 Kekerengu fault surface rupture through a homestead in Clarence River Valley. Photograph by Nicola Litchfield (GNS).*

The homesteads on Farms A and C received minor content damage. On Farm A, the sewage system was cracked by earthquake shaking, but the damage was not considered severe until the winter rains about six or seven months later. Having mostly undamaged houses, helped Farms A and C recover. As a Farm C farmer commented:

> *"We were very lucky and if this house had been munted too that would have been a hell of a job. That would have been, mentally, really hard. But it was nice to come back at night to a nice warm house."*

Farm B's homestead received the same level of content damage as the other two farms. The situation was worsened by the reactivation of a nearby historic landslide. The farmers were aware of the danger and moved out of the house immediately. They described the impacts of the loss of their homestead:

> *"We haven't slept back in the house at all from that day [the night of 13th of November], we slept in the caravan for probably two to three nights. We had a lady who [farmer's family member] teaches with, her parents have a fifth wheeler. So, they brought that up for us and we parked that at the end of the lawn. And we lived in that until just before Christmas. They wanted it back to go camping…We had an old caravan; we purchased a new caravan that had a chemical toilet and a shower, hooked that up to the water. And we lived in that until the start of February. At that point [farmer's family member] had had enough of caravanning, so she moved out with the kids, which was when they went back to school. She moved out with the kids and didn't come back here until the middle of April, start of May when this got brought in [Rawhiti cottage]. So, we bought this as a unit and it came in on a truck. So, I lived by myself in the caravan from the start of February*

*until the middle of April, start of May. I've got a few days that I consider to be really happy, but one of the happiest days was when wife and kids came back. Baching by yourself after being married for eighteen years was quite cool for about for about two weeks and then it lost its [appeal]."*

The family on Farm B moved into a Rawhiti cottage purchased from the MBIE from April to October. The time in the cottage allowed them the time to consider their future recovery steps. They constructed a shed to be used as a three-bedroom home in August and were able to move in over school break in October. They also have plans to construct another larger homestead and keep the house shed as a guest house. The new housing allowed them to develop plans to hire a full-time employee and perhaps expand their economic profile by renting it out to vacationers.

Damage to the homestead has significant impact on mental/emotional wellbeing. Conversely, having a safe home, even a temporary cottage, is enough to allow for clearer and calmer future planning. Outside organisations can help alleviate some of this stress by providing temporary housing.

#### *4.4.1.3 Fencing and Other Infrastructure*

Farms have a variety of infrastructure scattered across their farm, including: fences, essential service components like water tanks and obsolete or repurposed infrastructure. Damage to this infrastructure considerably adds to the overall cost, in time and money, of recovery, and can slow the repair of the main farm buildings. In some cases, this damage may pose a more immediate threat to the functionality of the farm.


*Figure 17 Earthquake and coseismic hazard damage to farm infrastructure. (a) Surface rupture through a fence. 16 November 2016 (b) Surface rupture partially under a shed and through a fence. 19 January 2017 (c) A silo shaken off its legs and foundation. 3 April 2017 (d) A broken plastic water tank. 5 May 2017. Photographs by C. Fenton.*

Fences are the backbone of farming and directly related to land productivity. They are costly and time-consuming to construct and maintain. In the case of property boundary fences there is an additional cost from the need for detailed land surveying. Fences are designed with particular livestock in mind. Cattle fencing is the simplest as it uses one or two electrified lines. If the cattle are trained then the fence might still work if the power is down. Sheep fencing must be high enough that sheep cannot jump over and tight enough in weaving and to the ground to prevent the sheep escaping. Deer fencing, though not present on any of these farms, is like a much taller version of sheep fencing. The fence's complexity changes how easily it can be repaired and how much it's repair is a priority for the farmer. Prices for fences vary depending on type and topography (The AgriBusiness Group 2016).

All three farms experienced varying degrees of damage to fencing. As almost a third of a million dollars had been spent to upgrade Farm A's fencing and water infrastructure immediately before the earthquake, the losses were relatively greater than on the other farms.

Fences were also impacted by on-going hazards (e.g., landslides and landslide dam breach flooding). When the smaller landslide dam lake on Farm A burst in mid-April, fences and floodgates downstream were washed out. This damage was covered by flood insurance. Damage to fencing has a long-term impact on how the farm will run moving forward, as a Farm A farmer explains:

> *"I've fixed the same fence three times. Slipping land. We have ripped out fences. They've obviously been damaged, but we've reinstated them onto the top of ridges. That hasn't necessarily worked because we've had a lot of damage on top of ridges as well. But in the overall bigger picture we will deintensify our land. Change our stock class. And we will probably end up running less livestock."*

The Farm B farmers strategically prioritised stock proofing several blocks and postponed repairs likely to be reversed by of reactivated landslides. Importantly, they also took the risk of delaying repairs to some boundary fences.

Boundary fence damage potentially has a greater impact than internal fence damage because it also carries a biosecurity risk. A neighbour's ram, for example, entered Farm A through a damaged boundary fence and caused a double lambing. Boundary fence repairs depend on relationships with and the impact/recovery situations of the neighbours as well. A farmer described the relationship variables:

> *"Then 'cause you're dealing with large boundary fences, some people are really active and pragmatic and they want to get it done too and others don't. It could be based on their financial position, they might be more exposed to debt than you so they just don't want to do it. So, there's lots of different relationships in the boundaries."*

The Farm B farmers and their neighbour had the same mindset with regards to their boundary fence repairs and were able to successfully manage a damaged boundary fence through the winter rains. They found that their mutual postponement allowed them to avoid the multiple repairs that others had to do in the face of ongoing slope movements. The farmer described the wait to repair boundary fence:

> *"A lot of the fencing has ruptured, with that landslide and stuff, and so we're going to have to get earthworks done to put a fence on it. We've got the same problem...do we send a contractor in there? On that land at the moment because of what could happen. And the other reason that we haven't done anything cause some of its boundary fencing was that we needed to let it get wet through the winter, stabilise itself a bit. Because a lot of people went in and ripped in if they've got their own dozers and stuff put the fence lines back in, put the fences up, the earth was still moving and all of that repair that they'd done, was done again. Luckily, my neighbour was pretty practical like me in thinking let's manage it but when it comes to actually putting the repairs in let's give it some time to work out what it wants to do because it may be that on a map and it would have to be resurveyed, I suppose, if one of us sold. That the fence is there, but the most practical thing is to put the fence out there. It's not good putting it straight through a bluff that's going to keep [moving]"*

On Farm A the implications of having to fence off all water sources in the future concerned the farmer. In hilly areas, these might be an unfeasible or costly annual project.

Fencing damage on Farm C was all internal, most caused by land deformation. This made it less of a problem. One farmer explained:

> *"We can't say fencing is a problem here. No. No. There's still fencing to be done. The cattle yards, down the road, where they used to, between the gate and the post, they used to shut against each other there's a gap like that, you know, 7 or 8 inches. And you can't see any cracks in the ground, no sign of anything. It's just, the ground has just stretched. So, we've got all that sort of thing. There's posts lying over. But it's not a biggie by any means. It's not like the hill country where there's a sheep fence and it's big gullies through rubbish. Nah, it's pretty easy."*

Even so, all of the farmers anticipate that it will take years to tidy up.

Most of Farm C's damage was concentrated on larger structures, such as staff housing. Farms A and C both had employee housing on the property at the time of the earthquake. Farm A's building was for seasonal workers and was not inhabited at the time of the earthquake. Farm C had several staff houses that were fully occupied. Farm A's shearers' quarters was made immediately uninhabitable by a surface rupture directly through the middle of the building. All of Farm C's staff houses were damaged by the shaking and ground deformation, with at least one requiring a rebuild due to foundation damage caused by lateral spreading. The other houses are either rebuilds or repairs. As of January 2018, insurance claims on the Farm C staff houses were close to resolution. Their repair was not a major priority for the farmers while the dairy shed was still being repaired. There was also temporary staff accommodation was available in a Rawhiti cottage. However, the farm has remained understaffed as a result of this housing damage and the unavailability of accommodation off-farm. One of the farmers said:

> *"So, on the dairy side of it, we are pretty well staffed up. But I run the runoff side of it and I usually have two staff and I've got no one to help me. I rely on neighbours and contractors and that sort of thing this year."*

Many farms have a level of infrastructure redundancy. For example, there are three stockyards spread across Farm B. The primary purpose of this stockyard distribution is to limit the time lost herding the stock across the farm. They also serve the purpose of decreasing the overall exposure their stockyards have to hazards. On all three farms there are sheds or other old infrastructure that have been abandoned or repurposed. The Farm C farmers were able to use their old woolshed, which had been converted to storage after they changed from a sheep to dairy farm.

The miscellaneous infrastructure of a farm may not carry the same level of repair priority as the primary economic infrastructure and homestead, but it still plays a vital part in the running of a farm. Fences are life, legal, economic, water quality and biosecurity safety measures. Staff housing habitability influences the level of employed help a farm can bring on. Whether these be long term employees like the dairy shed, or temporary contract workers for seasonal or repair jobs. Old buildings can be repurposed during an emergency and may even display greater resiliency than newer buildings.

#### *4.4.1.4 Essential Infrastructure Summary*

Farms have several types of infrastructure: primary economic infrastructure, a homestead and miscellaneous infrastructure (*e.g.* sheds, fences, tracks). Primary economic infrastructure damage can put livestock at risk and hence impact the stability of the farm. Homestead damage contributes to the mental/emotional capacity of farmers to plan and execute their recovery. Damage to the other various infrastructure affects various farm systems and the farm recovery rate. Having a backup on-farm for infrastructure is not necessarily helpful because it can be damaged as well. Although the capacity of miscellaneous infrastructure to be repurposed to adapt for main infrastructure damage should not be discounted. Instead, having strong relationships with neighbours is the best form of resilience to infrastructure damage. The farmers on Farms A and C were able to use their neighbours and neighbour networks to work around their primary infrastructure damage. The Farm B farmers' trusting relationship with their neighbour allowed them to save money and time by managing an unrepaired boundary fence through the cascade triggering winter rains. The repair of infrastructure is dependent on the functionality of essential services.

### 4.4.2 Essential Services

Essential services—the utilities, and infrastructure via which these utilities are delivered, required for the farm to function—are the same regardless of farm type or location (water, power, telecommunications and transportation). Although the services are the same, sources and infrastructure vary between farms. These differences factor in to the vulnerability of each system. Restoration of these systems is essential to the continuing function of the farm.

#### *4.4.2.1 Water: Systems and Damage*

Water is the most important essential service to the running of the farm. It is used to supply animal and farmer needs, irrigate fields and perform animal husbandry tasks (*e.g.* chemical dipping to control external parasites.) On the three case study farms, water is sourced from groundwater on-farm or delivered by a county water scheme. Farm water systems have high exposure to hazards due to the location of pipes and water tanks. Topography, water source type and component position all contribute to the level of damage. Water supply is generally gravity fed. The consequent, location of water tanks on hills or ridges contributes to damage caused by earthquake shaking or coseismic landsliding. Earthquake ground motions are amplified by topography and water-saturated slopes are more prone to slope movement. Water systems require immediate repairs, but complete and total repairs can take years.

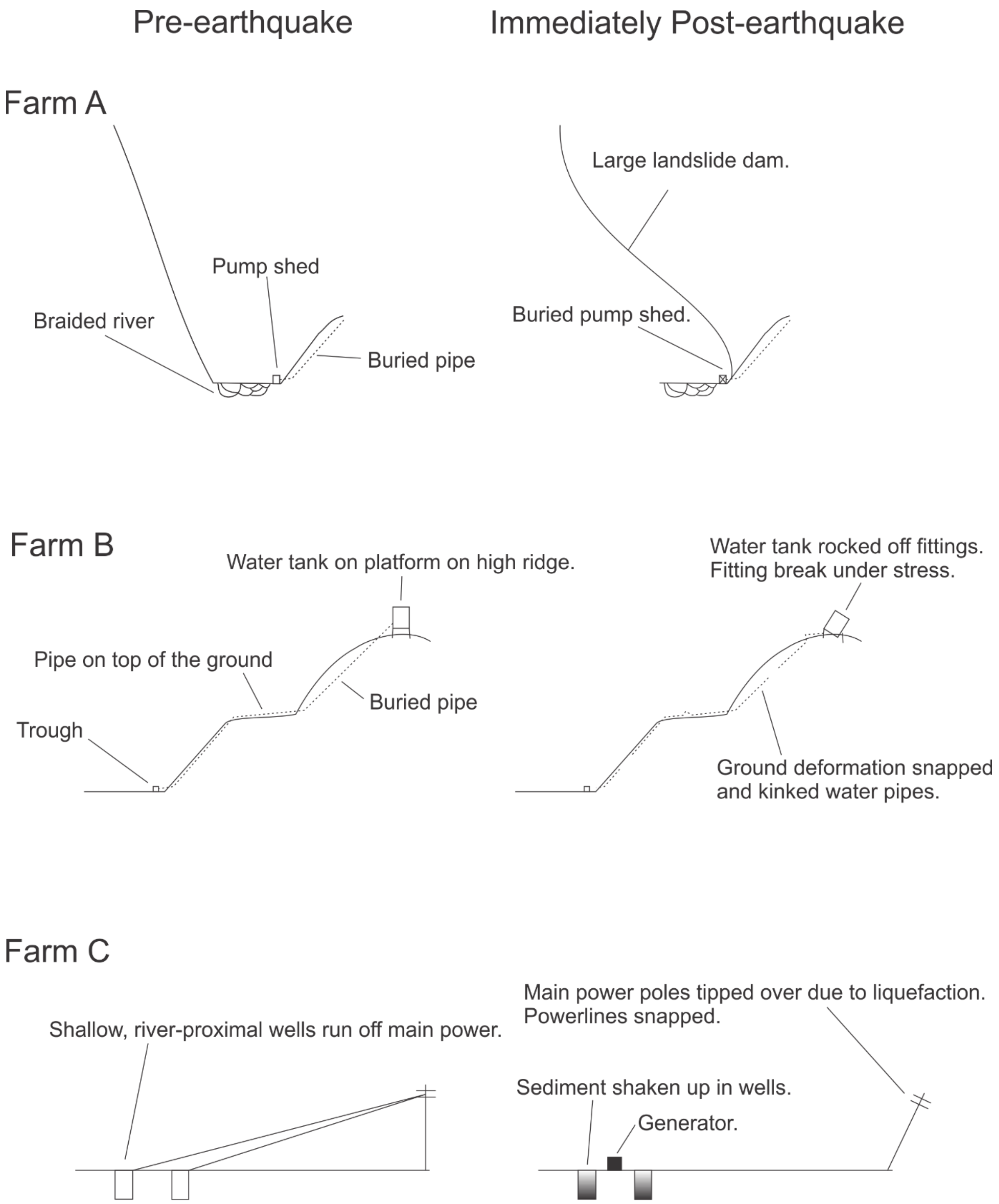



*Figure 18 Schematic cross-sections showing the water systems of the case study farms pre- and immediately post-earthquake. Farms A and C both had on-farm water sources. Farm used a pump by their main river. Farm C used shallow wells. Farm B used the county water scheme.*

Farm A and C source their water on-farm. On Farm A, a pump shed is situated near and draws water from its main river. On Farm C, several shallow groundwater wells are situated close to a major river. On Farm B, water is drawn from the county water scheme. This scheme is gravity fed, using water pumped from a major river into storage tanks high up in the hills. Each farm participating in the scheme pays for a daily allowance. The Farm B farmer has decreased the farm's dependency on the scheme by supplementing their water with on-farm dams in gullies to collect storm runoff. The dams also act as sediment traps.

On Farm A, the pump shed and generator were buried by a large landslide triggered by the initial earthquake. Farm C's power supply was disabled by the earthquake, so the well pumps could not operate initially.

The county water scheme was severely damaged by the earthquake shaking. The water tanks, mostly situated high on ridges, suffered from shaking damage exacerbated by topographic amplification.

Water system components- including water pipes, tanks and troughs were also damaged. Concrete tanks cracked during shaking. As they drained sand and pebbles from the concrete flowed through the pipes clogging the system. This meant that even undamaged pipes were sometimes clogged to the point of becoming unusable. Only three of Farm B's twelve water tanks did not break their fittings and 'rock off their platforms' during the earthquake.

Water pipes on all three farms were badly damaged. Some pipes snapped and others bent and buckled as the ground deformed. A farmer commented that damage to buried pipes went against traditional farming wisdom:

> *"'You always bury your water pipe as deep are you can.' All the pipes on top of the surface are fine. It's all the stuff we buried that's buggered. I don't mind that because it just tells me that you can't win sometimes and that's ok."*

As a consequence, they planned to adjust the way they constructed pipe systems moving forward.

One of the difficulties with fixing pipe leaks is finding them. Flushing lines with water is the fastest way and when the water tanks broke initially all the water drained. On Farm B, the farmers found that when pipes bent in areas of ground that at compressed there was no leak. So, finding the blockages was made even harder.

Ground deformations affecting fences also impacted water systems placed above the surface. The pivots on Farm C were the most impacted of the irrigator types because the slots allowing them to fit through fences were displaced by ground surface deformation.

Troughs used throughout farms to supply stock water were also damaged by earthquake shaking. Farm C's runoff troughs broke because the pipe connections between them and the tanks were too rigid to resist the earthquake shaking. Farm B's troughs were often clogged following the earthquake. Particles from imploded concrete water tanks had flowed through the pipes. The rubber grommets that were supposed to keep the troughs from draining were often found to have vibrated out completely or just enough to allow seeping.

The sewage systems on all three farms are buried septic tanks. The initial earthquakes partially cracked Farm A's septic tank. There were no major problems until half a year later when the winter rains arrived. Farm B's septic tank was abandoned with the homestead, so the damage was inconsequential. On Farm C, several septic tanks became buoyant as the ground liquefied and they floated to the surface. Notably, one of the farm's red stickered (declared unsafe for human habitation) houses had one of the still functioning toilets.

#### *4.4.2.2 Water: Recovery and On-going Impacts*

Much initial recovery time and energy was put into restoring water access. Checking each component of the water systems to find the damage took a long time. On Farm A, cascading hazards repeatedly undid the repair efforts.

The immediate water restoration concern on Farm A was accessing a new water source because the water pump had been completely buried and lost. A farmer commented on their use of a spring to do emergency repairs to their water system:

> *"...the water infrastructure was severely compromised. We didn't have water to a lot of the farm probably for six weeks after the earthquake. But that's sort of been pumped out of the river. Well, actually, we ran out of water completely because we had a side stream that we were able to put a pump into because the river had completely dried up. And then that side stream dried up. 'Cause it was the middle of the summer. We went out the back of the farm and we tapped a spring. And that supplemented what we were able to pump from the riverbed."*

Water system repairs were affected by on-farm transportation. All but two of the water tanks on Farm A had to be replaced. Due to the damage to the on-farm roads, the farmer had to bring them in themselves.

As part of the county water scheme, the Farm B farmers were not solely reliant on their own efforts. Civil Defence and the local council delivered tanker trucks of water daily to affected farms. This, a farmer said, is why water tanks should be installed close to easy road and track access. It helps outside aid deliver water for use and for repair. They described their water system damage and initial repair as follows:

> *"We've got all 25,000 and 30,000 litre tanks, which sit up high, which gravity feed all of the troughs. And out of the, I dunno, rough guess, 10 or 12 big tanks that feed the farm, might even be more than that, there was only three of them that didn't rock off their platform and so they broke all their fittings. So, 30,000 litres, 30 tons in a tank plus the tank it bounced literally up and down and they all moved about a foot. Half a foot to a foot and so all the fittings that are ridged had just snapped. So, all the water drained out of the tanks. And then trying to get them repaired, with no water, 'cause you've got to flush the lines to find the leak. And so, we had four-wheel drive fire tanker trucks, us and everyone in the area really, running 'round farm tracks that, you know, weren't really designed for that fill up tanks to try and get some charge of water to flush them back down the lines."*

The Farm A farmers used a water company to install their water shed. The company sent over an engineer for five days in December to help repair the water system. Even so, they did not have a reliable and adequate water pump in place until the middle of January, two months after the earthquake destroyed their original water system. A month later their system was damaged again by the landslide dam breach and consequent flooding of the downstream area. The system was rapidly restored following this event.

Initial water supply recovery on Farm C was focused on restoring the power supply. Because the farmers owned a generator large enough to power a dairy shed, this was almost immediate. However, the wells took a while to start producing water because sediment shaken by the earthquake was still settling.

Following power restoration on Farm C the repair of individual water system components became the most pressing matter. One of the pivot irrigators was damaged when the terrace collapsed underneath it. The main water lines and runoff trough connections were broken and one pump had slipped. Repair of these major components and the pivot irrigator was achieved within a month. Restoration of irrigation systems was vital to farmers because silage production was a key financial avenue for them while their dairy shed was being repaired. One of the farmers commented on their irrigation loss and restoration impacts:

> *"We had no irrigation for a while. So, that meant it we were quite dry, but we were able to look after our own stock. Then after we got our irrigation going we had silage to sell, so that gave us a little bit of income. And then we, because it was quite a good growth season, nobody needed any grazing until February. And then it got a bit dry, so people were after grazing so we had about 1600 on here grazing, which gave us a little bit more income."*

Water pipe repairs are time-consuming and costly. On Farm B, the farmers finally stopped trying to find the main leaks and simply brought in new pipes and tanks. The amount of time and cost of having contractors walk the property searching for leaks was considered to be too great. They also took the opportunity to put more of their own money into the system and improve it by replacing decades-old concrete tanks with plastic ones and adding more troughs. Even the new plastic tanks posed problems. When the fittings were drilled from the outside of the tanks, plastic fell into the tanks and clogged pipes. A few weeks before, the original concrete tanks had imploded. The fines and pebbles of the concrete had been sucked through the pipes and clogged them.

On Farm B, farmers were able to draw on system redundancy upgrades made before the earthquake in response to the drought. The farmer described this back-up system:

> *"So, second year of the drought we had to- We have a river at the front and a creek that runs through the farm and we had a lot of springs that flowed into wet areas, which stock could get water from 'cause we're on a county water scheme here for stock and house water, so if that broke down which it does do and it got completely destroyed in the earthquake, so it wasn't running for quite some time. We always had the ability to put the stock where water was. Because of the drought the creek had completely dried up, there was nothing left. The wet areas were dry. We had a couple of springs that were still flowing, but they weren't flowing enough to create water. So, in the second year, we had to start putting a water scheme over the far side of the farm, which was an area predominately done with natural water, so we'd put a whole new scheme in. And luckily, for me, that end didn't get damaged in the earthquake and what we were able to do was tap into the new infrastructure and bring it back this way. "*

Much of the farms' water systems were uninsurable. This contributed a reduction in water system restoration speed.

All three farms noted that despite now having functional water systems, it will take many years to restore them to pre-earthquake levels of functionality. This included acknowledging that the new water source will inevitably have problems in the future.

### Farm A farmer on the future of water:

> *"Anything to do with that river is always going to be vulnerable. It's just- we've already fixed the pipe a couple of times. Water is just an on-going thing really, it just doesn't go away."*

### Farm B farmer on the future of water:

> *"So, we had the initial earthquake, we had fractures that got fixed, but obviously a lot of stuff got stressed. So, we are forever finding wet patches where the pipes have just got tiny, little splits or have just got holes in them."*

### Farm C farmer on the future of water:

> *"Water systems here. We are still working with water. We will be for a long time, finding leaks and finding broken hoses and pipes. That's going to on-going for some time."*

Seasonal system repair is part of a farm's annual calendar. The earthquake damage has increased this workload.

#### *4.4.2.3 Water Summary*

The impact of an earthquake on farm water systems is dependent on water source type and farm topography. If a farm sources its water on-farm through wells or drawing from rivers, then a backup system is vital to reduce impact. This can mean having multiple wells, water sheds, or having backup parts and generators on hand. If a farm receives water from a community water scheme, then making the on-farm water system components as accessible as possible is key to aiding post-earthquake recovery. Easy road and track access makes truck water delivery and system repair easier. Farms with steep slopes will have more reoccurring issues with water systems post-earthquake. The chance of landslides, landslide dams and damage from topographic amplification are higher. Regardless of farm type or location, the water system is a vulnerable and vital asset that may suffer long-term damage following an earthquake.

#### *4.4.2.4 Power: Damage and Recovery*

Power is required to run the major economic infrastructure of a farm, any electric fences, telecommunications and the homestead. Power outages are a common winter and cyclone season occurrence, so most farms are prepared to operate without off-farm sourced power for a number of days throughout the year. Some farmers are moving towards increasing the length of time their farms can run independently by using generators and solar panels.

Many power poles were damaged during the earthquakes. Farmers on Farms A and B noted that they were prepared to cook and run their homes without power for several days at a time. Farm C has a generator powerful enough to run the dairy shed or the irrigation system. Power was restored to most of the district within the first week or two. Power restored to Farm C within four days. Farm B’s woolshed never actually lost power, but deformation of the ground below the power poles decreased the clearance and meant that the power to the shed had to be disconnected. It was restored in April 2017 when insurance was finally settled. Farm A, the most geographically isolated, spent the longest amount of power without to most of the property. Power was not restored until early December 2016. Farm A’s isolation has led to the farmers developing a level of essential service self-sufficiency. One farmer described their situation:

*"We would probably budget losing power nearly a month a year. We're an isolated farm that are subject to snow and wind and tree fall. And being two families, they always fix everyone else first. So, we are just geared up to be a little bit self-sufficient. I think when looking to the future, when we rebuild. We are looking at trying to be more independent with our energy sources."*

They also built in the ability to switch their homestead to run off a generator rather than the mains. They are looking for ways (*e.g.,* solar panels) to become even more self-sufficient with their power in the future.

The regional power company repaired the power systems remarkably rapidly in light of the level of damage experienced across the district. The more isolated farms in the hilly country were the last serviced, as expected. The Farm A farmers acknowledged that being more self-sufficient with this aspect of their system, is the most resilient option.

#### *4.4.2.5 Telecommunications*

Telecommunication systems are reliant on regional and local power. Mountainous areas limit the accessibility of cell phone signals. Landlines are frequently disrupted and the on-going unreliability has led many farmers to abandon them.

Farms A and C had on-going issues with landlines reliability following the earthquake. The Farm B and C farmers were able to use cell phones. Farm B did not have a landline and ran all of its telecommunication and internet off a nearby cell tower. Cell phone services were disrupted for only a few days after the earthquake. On Farm A, the farmers needed to go to the front of the farm or up to hilltops to obtain cell phone reception. They accepted that their situation is marginal due to their farm's distance from any major towns and the 10km distance between their homestead and the main road. They said they relied on radios, satellite broad band and the ability to switch their house to run off-grid if need be.

All three farming families reported moving towards telecommunications systems with reduced vulnerability. This was being accomplished through digital or satellite telecommunication rather than landlines and increasing power self-sufficiency.

#### *4.4.2.6 Transportation*

Transportation refers to both access to the farm (off-farm transportation) and access within the farm itself in the form of tracks and roads (on-farm transportation). Although access to Farms A and B was affected by a CDEM roadblock for several weeks after the earthquake, none of the three farms experienced major and long-lasting isolation. Damage to on-farm tracks and roads increased with topographic variation.

The farmers stated that on Farm A 99% of their roading was damaged by the earthquake; both fault rupture and landsliding impacts their tracks and roadways. They lost their main route of access to the paddocks at the back of their farm due to a large landslide. Travel time to those paddocks changed from a couple of hours to more than a day. In the winter, the possibility of mudslides makes safe passage nearly impossible. The farmer had to adapt by mustering their whole farm when they shear rather than just one or two paddocks. They noticed that normal drainage patterns were disrupted and the places where the ground previously moved during heavy rainfall have changed. Clearing on-farm access immediately was essential for the farmers, not only because access made repairs easier, but also because they needed to finish tailing.

By contrast Farm B's on-farm transportation suffered only minor impacts. All of the other infrastructure was damaged, but on-farm access was not impeded.

The Farm C farmers reported that extensive liquefaction damaged their main off-farm road access. This road was fixed and repaved within six weeks by the local council.

Transportation systems were key to any part of the farm being repaired. Off-farm roads are under the jurisdiction of local and regional councils. They were cleared and made passable relatively quickly. On-farm track and road access was a little more flexible. Farmers frequently had 4WD and motorbikes that facilitated off-road access. Repairing annual weather-related damage was an expected part of farm maintenance. Farmers typically had a sense of which areas were prone to slipping on their farm. The earthquake-related ground deformation changed the drainage patterns. The farmers needed to learn the locations of the new landslide prone zones. Level of access damage varied from farm to farm, lower lying areas (Farm B and C) had fewer issues than upland areas (Farm A) who had large landslides and surface ruptures cutting off sections of the farm. Repair and replacement of these tracks required attention to landslide reactivation and new drainage patterns.

#### *4.4.2.7 Essential Services Summary*

Essential services were vital to maintaining farm functionality and facilitating repairs. Water was the most important resource, but strategies regarding resilience and repair vary depending on source and system infrastructure. Regardless, having backups of the other essential services had a positive impact on water restoration and maintenance. Backup power sources, generators or perhaps solar panels, helped fill the gap while power was being restored to and across the farm. The farmers found that digital based telecommunication was more resilient than landlines, although reliability still varies for the more geographically isolated. Access was key to infrastructure repair. It was reliant on heavy machinery (*e.g.*, bulldozer or excavator) availability and roading redundancy. All three farms reported taking steps to increase the resiliency of their essential services.

### 4.4.3 Livestock

Farms cannot function without their essential infrastructure and services, but their continued economic viability is dependent on their livestock. Livestock refers to all farm animals that are an economic asset. The three farms have sheep, cattle, dairy cows and bees. Livestock are at risk of death, injury, disease and becoming lost in the aftermath of a disaster. They were the farmers' second priority, after human life, during immediate aftermath of the earthquake.

#### *4.4.3.1 Bees*

Bee hives are fast becoming a common sight on farms throughout New Zealand (Brown *et al.* 2018). They require very little infrastructure and maintenance for the high profit their honey returns. Bees can also take advantage of land that may be too hazardous for other livestock to use. Land that a farmer retires and returns to native bush does not lose productivity if bees are on the farm.

Farms A and B have bees on-farm. Bees produce honey between November and March, but begin flying in November. They require very little infrastructure and their hives can be installed across a farm to take advantage of wild foliage that other livestock cannot.

At the time of the study, the farmers on Farm A and B contracted with third party beekeepers. The Farm A farmers said they had plans to do beekeeping training and bring in their own hives. One farmer commented on how this decision affected their risk:

> *"We have decided that we see beekeeping as a future here. We've bought some hives. [Farmer] is doing some training. 'Cause it just changes the risk profile because bees don't need infrastructure. I think beekeeping has*

*a massive future. I just think anything to do with real food and nature operating in a system has got to be good to be involved it."*

During the earthquake, most of the beehives fell over. Resetting the beehives was one of farmers' first priorities. With the help of a helicopter this was completed within 48 hours. Although beehives are vulnerable to floods and landslides, they can be relocated to avoid these hazards.

Bees present an excellent opportunity for farmers who have lost otherwise productive land to landsliding and surface ruptures. The infrastructure and upkeep for bees is relatively low. They can use damaged land that has been allowed to regrow native plants (*e.g.* Manuka).

As with all livestock, bees can be vulnerable to hazards (*e.g.* floods, earthquake). However, their small infrastructure footprint and low maintenance requirements make them an excellent investment for farmers hoping to utilise 'lost' land.

#### *4.4.3.2 Dairy Cows*

Dairy cows numbers within New Zealand increased by about 128% between 2006 and 2016 (Statistics New Zealand 2017). Despite the minor slowdown from the previous decade in the overall stock number increase, there are still a significant number of dairy farms in the Hurunui District (Statistics New Zealand 2013a). High profits can offset high infrastructure and maintenance requirements (Wales & Kolver 2017).

There are one thousand milking dairy cows on Farm C. Several hundred young cows are kept on the runoff. These young cows are rotated onto the milking platform when they mature.

Dairy cows are heavily infrastructure-dependent as they require low relief, irrigated land and a dairy shed. Farm C's dairy shed is used for milking 10 months of the year (August to May). When lactating, a cow cannot go unmilked for more than about three days without developing mastitis, a painful and often deadly infection in the udder. The main earthquake occurred in the middle of milking season, so farmers were not able to dry off their cows. They were also in the process of artificially inseminating (A.I.ing) the herd. Disruption of even a day during this process can mean missing a cow's fertile period and necessitate waiting for the next cycle. They needed to be able to continue this process or hand it off to someone who could. The farmers called on their management team (Farm Advisor and Bank Manager) to help them relocate all one thousand of their milking cows. Their efforts were successful and every cow had been shipped to another farm and milked within 48 hours of the earthquake.

The effort of relocating the cows was complicated by the damaged telecommunication systems and the specifications of the receiving farm. Dairy cows are reluctant to enter new dairy sheds, so the ones they were sent to had to be identical to Farm C's. The milking sheds on the receiving farms had to be rotary sheds that rotated the same direction as the one on Farm C. The receiving farms also had to have to capacity to hire on more staff to handle to stock influx. One of the farmers described the teamwork:

> *Farmer C1: "So, you know that's what the bank manager and farm advisor were doing. So, there was a lot of work in it. They would ring out. Well I suppose they knew who had what types of sheds… "*
>
> *Farmer C2: "Then their staff had to have extra staff. Calling in staff to get the milk because they won't go in a new shed. So, there's a lot of work to be done there. And they had to be A.I.ed too. The next day they had to bring them in as a mob and check them. So, a lot of work done by a lot of people."*

The dairy cows began to be sent back to them in April, as they dried off. In late July, a few of the cows calved early, but once again the farmers were able to call on their neighbours for help. A neighbour's milking shed was borrowed until the new dairy shed was completed and functional on July 28th.

Dairy cows are the most vulnerable to hazards (*e.g.,* floods, earthquakes). They have large, expensive and intricate infrastructure and high maintenance requirements. Dairy cows have a strict annual calendar that means their level and type of impact is slightly variable. Farmers must be prepared with a large support network and management team to navigate post-disaster recovery.

#### *4.4.3.3 Beef Cattle*

Beef cattle in New Zealand have decreased 82% over the last ten years (Statistics New Zealand 2017). Sheep and beef farms still make up a significant section of Hurunui District farming (Section 1.7.2.1 ). Beef cattle have lower on-farm infrastructure and maintenance requirements than dairy cows and sheep.

All three farms have cattle. Farms A and B have exclusively beef cattle. Farm C's cattle are a mixture of beef and future dairy stock.

The main cattle infrastructure is fences. Cattle fences are the simplest and easiest to maintain fences. A Farm A farmer commented on cattle fences:

*"[With] cattle, you can put one wire up as high as your hip and they will generally stay behind that wire, if they're trained. The ability to reinstate that sort of infrastructure after an event is quite simple. Because you can almost pick it up and bang it back into the ground."*

They mean that a single wire fence might still work even if it is not electrified. The initial priorities for beef cattle include water access and fence restoration.

Beef cattle are vulnerable, however, to ground deformation and fissures. Farm B lost several cows to a partially covered fissure.

Beef cattle are the second most resilient of the livestock covered in this thesis. They have a low infrastructure dependency. Their lack of a rigid annual calendar, outside artificial insemination and calving, make their year-round vulnerability relatively equal.

#### *4.4.3.4 Sheep*

Sheep in New Zealand have increased 140% over the last ten years (Statistics New Zealand 2017). Specialised sheep farms and sheep and beef farms still make up a significant section of Hurunui District farming (Section 1.7.2.1 ).

Farms A and B have several hundred sheep. Farm B lost approximately 150 sheep to surface ruptures and landslide fissures during the earthquake and to other causes within the first few months. The farm's exact loss numbers are uncertain. The farmer described the earthquake's impact on their sheep:

*"Sheep tend to camp up at night. So, they were probably camped up on the crests of hills. The shaking would have been worse on the tops I imagine than the bases. We found the odd sheep where the cracks, something had come through, it's opened. Whether a sheep fell into that crack or whether it was asleep and the cracked just opened around it, but they'd opened and closed so we found pancake sheep. The dogs found a lot of sheep about two and three weeks later that had probably fallen into crevices were alive, but literally couldn't get out. So, as they died, and we didn't know they were there. We found a lot of the cracks in the weeks afterwards and as they died of course they started to decompose and with dogs being dogs they could pick up the scent. I don't know how many sheep we would have lost in that. Nowhere near as bad as some of the people up round Kekerengu and that. That's a bit of an unknown really."*

Sheep infrastructure is more complex than bees or beef cattle. Sheep farms must have an operational woolshed. Unlike dairy cows, a woolshed is not used daily. Both the Farm A and B farmers spread their shearing out over several months to decrease their risk. The Farm A farmers missed a planned shearing when their woolshed was rendered non-functional by the earthquake. However, they were able to use a neighbour's woolshed. The farmer described this event:

*"One of the first big events we had. On the 6th of December we had to walk our sheep to our neighbours to shear them. And they're probably 10kms away. And we were offered their help, the free use of [their] woolshed, which was really pleasing."*

Farm A's woolshed continues to be non-functional. As a result, the farmers have had to delay shearing some of their sheep. The wool deteriorates in the meantime because sheep will seek shade in summer and become covered in vegetable matter as a result. The wool price decreases as it deteriorates. Business interruption insurance can help address the deterioration gap.

The loss of water access had more of an impact than just dehydration for Farm B's sheep. The process of fly dipping typically uses water-solvent chemicals. The farmers delayed dipping as long as possible, but eventually had to resort to dry chemicals. Their wool prices suffered as a result. A farmer described this:

> *"So, we had to use a range of chemicals that don't require water. They came at a far greater expense and their efficiency is far less. And then you have withholding periods because they're a different sort of product that effect your ability to kill animals for meat…so everything got turned upside down."*

Like cattle, effective sheep husbandry requires fences and stockyards. These are more complicated than the cattle versions to repair. A Farm A farmer commented on the resulting farm plan impacts:

> *"We'll be running less sheep because it's almost impossible now to keep sheep in a paddock. Because we've got all these cracks and they can fit through tiny holes."*

The farmers on Farms A and B had planned tailing to conduct at the time of the earthquake. On Farm A, friends and volunteers helped the farmers to complete this task less than two weeks after the earthquake. On Farm B, the farmers were able to do some emergency repairs to their stockyards to complete these, but the more permanent repairs required more time.

Sheep are the second most vulnerable livestock on the case study farms, after dairy cows. Their annual calendar means that the severity and type of impact can change depending on the time of year the earthquake occurs. The sheep annual calendar does have some flexibility. Both sets of farmers spread out their shearing slightly to reduce risk. On Farm B, lambing and weaning was able to be shifted for climate and crop growth reasons as well. Strong neighbour relationships can reduce the initial impacts if infrastructure can be borrowed. Ultimately, woolshed repair is essential to sheep farm continuance.

#### *4.4.3.5 Livestock Summary*

Livestock hazard vulnerability varies. Their vulnerability depends on required infrastructure, maintenance and hazard timing. Livestock with variable annual calendar are more vulnerable to earthquakes at sometimes of year than others. The livestock present on the case studies farms, in order of most resilient to least: bees, beef cattle, sheep and dairy cows. To reduce a specific livestock's vulnerability, farmers can construct key redundant infrastructure (*e.g.* multiple stockyards) and build flexibility into their annual calendar when possible. As with other aspects of farm resiliency strong neighbour network, allow for resource pooling. For severely impacts farmers, they may consider more drastic changes such as reducing stock numbers or changing stock class. Alternatively, a farm may diversify their stock classes to reduce overall farm impact.

## 4.5 Human Factors

Human factors that influence farm recovery are the mental health of the farmers, endogenous support (*e.g.,* staff, family) and exogenous support (*e.g.,* government agencies, NGOs). Human factors change over the recovery timeline. Intense off-farm aid is more common early in the recovery process. Long-term, human resources are more internally based. On-farm and on-farm groups frequently interact and support each other. However, these relationships can also become oppositional or disruptive to the recovery process for an individual farm.

### 4.5.1 Mental Health

The mental health of a farmer and their community significantly impacts a farm's recovery process. The psychosocial trauma of the 2010 Darfield earthquake was found to more negatively impact Canterbury plain farmers' operational capacity than the earthquake's physical impacts (Whitman *et al.* 2012). Sleep deprivation, decreased focus and uncertainty were reported as the most frequent side effects of stress. This study did not set out to explore the mental health impacts of the Hurunui-Kaikōura earthquakes. The semi-structured interviews allowed the participants to discuss them as a significant part of their farms' recoveries. The internal and external stress and support factors changed over time (Table 9). The factor changes influence and are influenced by the farmers' recovery decisions.

*Table 9 Earthquakes have a major impact on the mental health of farmers. The recovery process itself is a source of stress. Some of the contributors are internal to the farm and others are external. A farmer's mental health impacts their ability to proceed with recovery.*

Mental Health Factors

| | Internal | External |
|---|---|---|
| Pre-earthquake | Farmer personality<br>Farmer experience<br>Infrastructure status<br>Financial performance | Climate (Drought)<br>Geography (Isolation) |
| Earthquake/ Short-term | Life safety (livestock, staff and family)<br>Emergency repairs/clean-up (short-term hyper focus)<br>Infrastructure Damage<br>Safe Home | Community<br>Assistance quality<br>Outside attention<br>Access Restriction |
| Long-term | Future/children/opportunity/planning<br>Momentum/fatigue/on-going<br>Time | Community<br>Assistance quality<br>Insurance process/Finance<br>Climate<br>Isolation/loss of attention |

#### *4.5.1.1 Pre-earthquake*

The pre-earthquake mental health factors are farm and farmer characteristic based. Geographical isolation has a negative impact on farmer's extensive networks. It contributes to developing a resilient attitude. All three farms adapted their essential service sources in response to their isolation levels (Section 4.4.2 ). The North Canterbury region experienced a drought for the two years before the earthquake. The financial stress of the drought impacted Farms A and B the heaviest. The farmers' mindset heading into the earthquake was a product of personality and experience. This contributed to their baseline stress levels. The Farm A farmers found themselves being not optimistic after dealing with drought and low economic returns for several years preceding the earthquake. One farmer commented:

> *"I think your optimism comes with financial performance and we've had four or five years of really poor prices..."*

#### *4.5.1.2 Immediate/Short-term*

Immediately after the earthquake, the main stress factors were the earthquake itself and coseismic hazards. Outside aid, family and timely competent emergency aid and repairs helped combat this stress. Even so, the multiple sources of stress built-up and combined to occasionally overwhelm farm and farmer recovery capacities. On this cumulative stress, a farmer said:

> *"So, this is all happening while we're still in drought. We had to get stock off farm because it was having a major implication on being able to carry them forward without them losing weight because we were fast running out of grass. We couldn't even get a truck in to get the stock off farm. We were going to have to take the stock somewhere else. But, where were we going to take them because they weren't letting anyone through the roadblocks. And then we had insurance that won't settle. And I can understand that you need to take some processes and some time frames around that, but insurance that won't settle. We are physically covering the cost, immediate costs ourselves, which is a bit of a burden on the cash flow, etc. and the fact that we'd run at some quite big losses for the previous two years because of the drought."*

Perceived incompetency, ineffectiveness and dishonesty of outside help was a major stressor. One Farm A farmer commented that working with new contractors whose competency was an unknown was a constant recovery stressor. They also felt isolated and frustrated by CDEM organisations asking the same impact assessment questions, particularly before and after the transition from local to regional control. This repetition raised doubts about how impact assessment information was being collected, coordinated and applied.

> *Farmer A1: "Then you got your rural support network where people come and just touch base with ya. We had a bloke turn up, he was a volunteer for civil defense, to talk to us and he wrote down what we thought our immediate concerns were."*
>
> *Farmer A2: "But then once civil defense national body took over they had to come back and ask us all the same questions again."*
>
> *Farmer A1: "I think I immediately realised that we were on our own."*
>
> *Farmer A2: "We didn't even think about it. It just needed to be fixed, so we just got on to fixing stuff."*

A Farm B farmer commented on their insurance company's email newsletters. They found the promised priorities did not match reality. This perceived dishonesty only increased frustration. Nevertheless, as one farmer said, the simple presence of people in the early days helped morale:

> *"And those first three or four days a lot of people came in to see how we were and all that and a lot of people that I didn't know. I was in amongst them, but I didn't speak to them. But it was always good to see a face further away. You knew why they were there, just being supportive. So, it gives you quite a buzz, you feel better about it. You aren't sitting there by yourself."*

Farm B's homestead was left uninhabitable by the earthquake damage. The farmer's family moved off farm for a few months. This temporary separation had a negative effect on the farmer. The farmer commented:

> *"I've got a few days that I consider to be really happy, but one of the happiest days was when wife and kids came back. Baching by yourself after being married for eighteen years was quite cool for about for about two weeks and then it lost its [appeal]."*

The Farm C farmers recognised the mental benefit of being able to return to a habitable and relatively undamaged house every night. One farmer commented:

> *"…we were very lucky and if this house had been munted too that would have been a hell of a job. That would have been, mentally, really hard. But it was nice to come back at night to a nice warm house."*

They drew on the kindness and support of their staff, neighbours and wider community. On their staff, they said:

> *"So, I think it was really good that everyone was together. And the young boys, they showed up, they really rose to the occasion, didn't they? And lit the fire and got water and looked after people. We didn't know at that stage that the dairy shed- we didn't know the severity of the earthquake."*

The much wider community assisted as well. The farmers also praised a community aid initiative by the lottery board:

> *"And that lottery board grant, that was set aside from the lotteries in December. You know the proceeds were put in a fund. That's been wonderful for the community. Like, I'm a member of the tennis club and our tennis courts, they weren't totally munted, but they'd got cracks in them and we'd only just resealed them and we got money out of that. Various organisation have gotten money to do something in the hall or do something here or there. So, that's been great."*

In the early days of farm recovery, safety, human contact and kindness did a great deal to combat earthquake-related stress. The intensive activity of multiple off-farm organisations was generally beneficial to speed emergency repair, but all increased the chances of instances of hindrances or annoyances rather than aid.

#### *4.5.1.3 Long-term*

As farm recovery enters the long-term stage, the farms' and outside organisations' priorities and main focuses shift. Much of the regional and national attention retracts from the area, as emergency aid slows down. The loss of focus outside attention can create a magnified sense of isolation. One farmer said:

> *"When you've got 7 or 8 farmers spread over a massive area it's just got no political weight to it. There's just not that weight of pressure from even media to get things done and for justice."*

The Farm A farmers hired a lawyer several months into the recovery process. They found themselves in a prolonged insurance process and needed someone to help them develop a strategy to deal with it. According to the farmers, hiring a lawyer earlier in the process would have decreased their stress levels. A farmer described the lawyer's support:

> *"So, we are doing a due diligence process with them. In hindsight, I probably should have rung the lawyer within a week. It just looked at- even, you know, just put a game plan in place. Just a strategy. 'Cause I think I, personally, feel calmer when there's a strategy in place 'cause then it helps you deal with- it's just like this is what they are going to do and they are going to do this and this and this and when you see it happening*

*you're just like aw, you said that was going to happen, that's fine. Those are stories that people tend to share when they catch up and talk earthquakes."*

Time is vital to recovery. Not just spending the time to repair something but having the time to consider various options to rebuild or not, as the case may be. The Farm B farmers experienced an increase in mental time upon securing more stable housing:

> *"That gave us time, once we were out of the caravan to really start thinking about the situation, which was quite good so we were starting to think in terms of rebuilding, etc. Are we going to build a great big homestead? We got to look at what are we going to get paid out, what are we going to contribute? And we've been in the drought for two years financially we were really feeling the effects of that drought. It wasn't ideal timing. "*

After emergency repairs are complete, long-term planning shapes the mental health concerns. The prolonged focus required to conduct repairs and manage contractors and new staff drains farmer energy. In order to maintain recovery momentum, farmers are unable to take sufficient breaks to replenish their energy stores. A Farm C farmer commented that even with staff, they needed to stay on-farm:

> *"And we've found that it's important that you don't go away because if you do go away. Momentum just drops off. We want to keep it going and we need to be here every day. And with new staff, only one of the original staff the manager is new and the rest of the staff, so it was important that I was around. No water, well I know where to go or an idea of where to go to get it going again. Or where the cows go or the irrigation, I'd show them how to do the irrigation. So, it's put a lot of pressure on us, but it's always been that way."*

From the time of the earthquake to being interviewed in October 2017, the Farm C farmers had been able to take less than seven days total off. The exhaustion was building after working everyday every week for months.

#### *4.5.1.4 Mental Health Summary*

Earthquake event and recovery related stress has a compounding effect on mental health. A farmer's mental health in turn feeds back into their farm's recovery by diminishing their energy and recovery speed. There are many sources of stress and many avenues to address or alleviate it. The Rural Support Trust did excellent work organising community meetings and advocating on behalf of farmers. Farmers reported hiring lawyers early in the insurance process to at the very least put a strategy in place reduced stress. An unaddressed source of stress was the one that spring from the inevitable ending of intense outside support and concurrent loss national and regional media and public attention. The feelings of isolations this causes needs to be addressed. There needs to be recognition, research and expansion of mental health resource for rural areas.

### 4.5.2 Endogenous Support

Another form of on-farm resource is endogenous support. Endogenous support is all internal human factors. This encompasses personnel employed on-farm and management systems with a majority of endogenous components. Farm personnel may be contract, seasonal worker or full-time employees. A farm's ability to employ on-farm personnel can be impacted by the earthquake. Farm personnel are an essential part of farm recovery and a return to normality. The alternative to an exogenous management system (Section 4.5.3.4 ), is an endogenous management system.

#### *4.5.2.1 Full-time Employees*

Full-time employees work year-round and are frequently housed on farm. Their employment and housing is dependent on farm status. They are at risk of job loss if their housing is severely damaged or the farm losses its financial ability to keep them employed. The ability of farms to maintain full-time employs may fluctuate during the recovery process. At the time of the earthquake, only Farm C had full-time employees.

Most of Farm C's staff are full-time employees. At the time of the earthquake, there were about ten staff members. Most of the staff was housed on-farm with their families. Despite not having an on-farm emergency plan, the farmers and staff still met by the dairy shed soon after the shaking stopped. The farmers' first priority was to look after their people. The yard around the dairy shed became the gathering and cooking site during the initial recovery stages. While the dairy cows were off farm and the dairy shed was not operational, the farm could not afford to continue to employ most of the employees. All but one staff member, who was the second-in-command for the runoff, was let go. A employee wage subsidy fund from MBIE helped the farmers pay the staff their remaining salary until most of them left in mid-December. Their previous manager had left the month before the earthquake and their new manager had yet to start. The new manager's start date was pushed form December to May. By June the farm had re-staffed the dairy shed. In January 2018, one of the farmers was still managing the runoff by themselves. The damage to their staff housing had the knock-on effect of keeping the farm understaffed. The farmers also said that non-priority jobs had to be postponed because they were understaffed.

The Farm C farmers saw an opportunity to rethink their business model following the earthquake. Something they would not have had the opportunity to do if they had not had to let go most of their staff.

Farm B acquired a few new houses during recovery. A farmer mentioned they were considering using one to hire a full-time employee. Prior to the earthquake, they did not have the housing capacity to do so.

*4.5.2.2 Seasonal Employees*

Seasonal (or contract) employees are workers hired to complete specific jobs or for a season. They typically supply their own housing and transportation. The workers themselves are less directly impacted by damage to the farm because their employment is not dependent on one farm or maintaining function. A farm's inability to hire contract employees will significantly slow their recovery. The most common impact on the employment of contract workers was shifting the timing rather than eliminating their use entirely.

Seasonal workers are employed on Farms A and B for three main tasks: drilling, weed removal and shearing. Drilling timing is entirely weather dependent and takes several days in good conditions. In wet conditions, these tasks may stretch over a couple of weeks. Weeding for some plants, such as Nassella tussock (*Nassella* trichotoma and *Nassella* tenuissima), is legally required. This takes place over several days in spring to best avoid disrupting the young lambs. Contractors weeding must walk the whole property on foot. Shearing takes place throughout the year to reduce animal health problems. Crutching in November to December, belly crutching from April to May and shearing from mid-July to mid-August. Most of the seasonal work is done by contracted employees (*e.g.,* shearing, road maintenance, harvesting).

There are also part-time workers employed for general maintenance work on Farms A and B. On Farm A, they are employed for 3 days of the week. On Farm B, they are employed for the whole winter season.

The employment of contract workers is essential to completing vital farm tasks. The workload on these farms is too large for the farmer and their family to complete alone.

#### *4.5.2.3 Endogenous Management System*

An endogenous management system consists of the farmer, their family and on-farm staff. They do not employ off-farm managers like exogenous managements systems (Section 4.5.3.4 ). The farmers on Farms A and B both use this management system type.

This style of management is more flexible on a day-to-day basis. It lacks the far-reaching network of the exogenous management system. It consists of an on-farm manager, but it can also just be the farmer's family. A Farm A farmer described this system:

> *"I enjoy operating on a very short chain of command. I don't have shareholders or a board of directors to tell me what to do. I'm in total, obviously with Farmer 2 and a little bit with my in-laws, but I make all decisions. And I can make them in a heartbeat. It takes the pressure off because you're not being delayed to make decisions. I think that was helpful, to me. Because I know other people in the district when they've got owners and shareholders, it hasn't been as straight forward to prioritise what gets fixed and stuff like that."*

#### *4.5.2.4 Endogenous Support Summary*

Endogenous support is a key on-farm resource for reducing workload stress on farmers and maintaining farm functionality. It contributes to how a farm can be flexible at short notice. A farm's immediate resilience in isolated situations is heavily based on its endogenous support. Less isolated farms may rely on exogenous networks.

### 4.5.3 Exogenous Support

When the on-farm resources are drained or functionally-compromised, the farm must reach out to off-farm support. Exogenous support refers to people and organisations that influence a farm's recovery from the outside. This includes: government, insurance, NGOs, contractors and volunteers. It also refers to any management structure with exogenous components. Outside disaster periods these entities may have little or no contact with the farms.

*Table 10 Major active periods and contributions of each major exogenous organisation during the 14th November 2016 recovery period.*

Earthquake Recovery Contributions by Organisations

| | Major period(s) of earthquake recovery interaction | Major Contribution(s) |
|---|---|---|
| EQC | Short-term | EQC Earthquake Insurance |
| ECan | All | Surveys |
| MPI | Short-term | Uninsurables fund |
| MBIE | Short-term | Wage subsidies, Rawhiti cottage discount |
| Parliament | Immediate | Hurunui/Kaikōura Earthquake Recovery Bill |
| Local Council | All | Emergency declarations, Building consents |
| Insurance Agencies | All | Insurance |
| CDEM | Immediate | Emergency aid |
| Rural Support Trust | Immediate, Short-term | Morale and advocacy |
| Federated Farmers | Long-term | Community consultancy projects |
| Beef+Lamb | All | Community consultancy projects |
| Fonterra | All | Organisational support |

#### *4.5.3.1 Immediate*

The first six weeks after the earthquake contained the greatest contact with exogenous support. The national government announced and enacted legislation to aid the recovery process. Groups involved in emergency aid and repairs (*e.g.*, CDEM) were particularly active. Other organisation (*e.g.*, insurance companies, ECan, EQC) began their surveying work to inform their assistance during the later stages of recovery.

Community groups and rural support trust were actively checking on neighbours and delivering donated supplies.

Community

The community (family, friends, neighbours and volunteers) were the first to respond and be on-farm within the first few hours. As coseismic hazards to roads and roadblocks (implemented by CDEM) isolated several farms after the earthquake, these groups continued to be the main initial source of human resources.

Life safety was the first priority. Checking on family, staff and neighbours was the first action of all three farms. A Farm B farmer described the early hours:

> *"About between 1 o'clock and 2 o'clock in the morning we had enough cell coverage from texting and the odd broken conversation to establish contact with all of our neighbours. So, I knew everyone was alive. And everybody felt as though they were in an area where they felt safe in. So, that was my immediate concern was everyone else really. The next day is was just was well that everyone had reported in that they were okay because if we'd got through to someone and they'd been in danger. I think probably the biggest loss of life would have been getting to them. We didn't know that the road had ruptured completely and there would have been that much going through your mind, you would have just driven off bluffs and roads. There was areas of roads that weren't there further up, that if people had tried to go and help someone probably in the dark, if might have ended up being a bit of a disaster, I think."*

Neighbours and volunteers were a significant source of equipment and workforce during the initial repair stage. One Farm A farmer commented:

> *"I had some volunteers come up from our building company…and we tailed our sheep in the yards on the 26th. That a pressing job that needed doing. I just rung one of my best mates and he just brought his company up and we smashed it out."*

Farm A's woolshed was too damaged to be used. The farmers were permitted to use their neighbour's woolshed to complete planned shearing. They described this event:

> *"One of the first big events we had. On the 6th of December we had to walk our sheep to our neighbours to shear them. And they're probably 10kms always. And we were offered their help, the free use of [their] woolshed, which was really pleasing."*

Much of Farm B's early water system repair progress was thanks to an excavator that had been on a neighbour's property at the time of the earthquake. Because of the roadblock, the digger was unable to leave and so, the farmer was able to borrow it. Also, Farm B's first temporary accommodation, a caravan, after the homestead was deemed uninhabitable was borrowed from a family friend.

Government

The Ministry of Business, Innovation and Employment (MBIE); the Ministry of Primary Infrastructure (MPI); Environment Canterbury (ECan); Civil Defence and Emergency

Management (CDEM) and the local council were the most involved parts of government in the recovery process. Most of the national governments immediate support was in the form of announcing funds that came into effect during the short-term recovery stage. Representatives from all off the groups were on the ground at some point.

The first government organisation on the ground was CDEM. They were responsible for checking life safety and attending to basic needs. A Farm B farmer described their initial interactions with them and their aid in bringing attention to their landslide risk:

*Farmer: "So, [Insurer] did an imminent risk report 'cause we made- Who are the guys that come in…? [The Government Department]. So, they came in and they started door knocking, a few days after the earthquake to make sure A) is everyone alive and B) do you need anything essentially because the road was all beat up and no one was getting through they had it closed off. So, [The Government Department] were doing the rounds by that stage, getting water, whatever. They came in and I said, 'Look, I'm a bit worried about this hill.' They came back well we're not qualified to answer that, so they sent up two guys that were contracted [The Government Department] and they were from…doesn't matter, I just can't think of the two companies."*

***Researcher: "[Engineering Company]?"***

*Farmer: "No, [Engineering Company] worked for [Insurer]. There was a couple of other companies that obviously [Insurer] had contracted in they were going 'round looking at bits of unstable land, or whatever. So, they came in and did a rapid response report and said, "Yeah, no we're not very happy. That we've got to be a little bit careful with what could happen there."*

The most significant and broad impacting action by the national government was the Hurunui/Kaikōura Earthquakes Recovery Bill.

The Farm C farmers used MBIE's employee wage subsidy fund. Following the earthquake, they had to let nearly all their staff go because without a functional dairy shed they could no longer employ them. The wage fund allowed them to keep paying their staff during the letting go period.

Not all aid from government organisation was perceived as helpful. Some miscommunications were reported during the initial recovery stage. Farmers reported redundant action and contact was irritating. Farmers on Farm A described how this redundancy affected them:

*Farmer A1: "Then you got your rural support network where people come and just touch base with ya. We had a bloke turn up, he was a volunteer for CDEM, to talk to us and he wrote down what we thought our immediate concerns were."*

*Farmer A2: "But then once CDEM national body took over they had to come back and ask us all the same questions again."*

*Farmer A1: "I think I immediately realised that we were on our own."*

*Farmer A2:"We didn't even think about it. It just needed to be fixed, so we just got on to fixing stuff."*

In addition, although necessary for hazard zone control, the roadblocks by CDEM also had the negative side effect of restricting access to some farms. Farm A and B were behind the roadblock. Their farmers experienced a few weeks of frustration as contractors and sometimes even their fellow farmers, who also resided passed the roadblock, were unable to use the road. One of the farmers described the roadblock's initial impact:

> *"Well they blocked the Leader Road at both ends. It wasn't us. That happened one or two days afterwards where people who wanted to come see us or help us, couldn't get though. It felt like there was a window where it felt like you could do whatever you liked for about 48 hours and then it just sort of clamped up."*

Contractors, Consultants and Suppliers

All three farms employed contractors to carry out their repair projects and bring in supplies. Pre-existing relationships and trust became a reoccurring theme.

A contractor was responsible for much of the farmers' initial difficulties restoring Farm A's water pump. One farmer described this:

> *"I was having ridiculous problems with the pumps. So, we spent six weeks of just, this guy who was over his head, ordering, you know, crap stuff. I just expected that it wouldn't be that hard to find a pump that could pump for twelve hours. And he had this pump that turned up, it could hold a litre of petrol. And then it couldn't lift enough water to the woolshed. So, we had two pumps going. And then when he sent the bill in I refused to pay it 'cause I was 'you're a muppet.' So, when we got a generator and a proper pump on site on the 14th of January that was the first point where I felt as though we had a reliable source of water. Wasn't 'til the 14th of January."*

The farmers had a much better time working with contractors with whom they had pre-existing relationships. Their responses were quick. However, farmers could not always work with their trusted contractors. This problem was caused by the fact that there was such a big call for contractors. Farmers may not implicitly trust new people whose competency they were not sure of. This led them to often closely manage repair work. This added to stress levels and interfered with essential farm jobs. A Farm A farmer commented on this:

> *"The frustrating thing for me was you don't get your regular guy, they bring in a lot of support workers. And I had to stand in front of that bulldozer and those machines and I didn't trust them to do what I wanted them to do and in a lot of cases when I went away the wrong thing was done…Part of me felt as though I should have just been driving the machine myself. But there was a massive tie. I couldn't really leave anyone to get on with it. And then I got a bit angry because I asked a contractor stop because I wanted to harvest our lambs and just keep the business running. And he threatened to take the machine away. You know, probably thinking it could be used somewhere else. Yeah, but then it gets busy somewhere else and it doesn't come back."*

Attitudes from suppliers covered the spectrum from focused on making money to being supportive. Some farmers reported problems with suppliers hiking prices post-earthquake. Their regular suppliers were less of an issue. Other farmers said the found that many suppliers were willing to offer discounts.

Agricultural Businesses and Organisations

During the initial recovery stages, agricultural businesses and organisations were present on farms to offer various forms of support. Farmer membership or participation with them tends to depend on farm type. A Farm A farmer commented on Beef+Lamb's aid:

> *"Yeah, Beef+Lamb are good. They gave us the helicopter to use. That was sponsored. The helicopter just turned up and someone said do you need to go for a ride, so that was pretty cool."*

Farm A is a large farm (>2000ha). The helicopter offered the opportunity for the farmers to conduct an aerial survey of the damage caused by large landslides and surface rupture across their property faster and safer than they would have been able to on-foot.

Some of the assistance was less vital, but still appreciated. Farm C farmers are a part Fonterra. About Fonterra's assistance on the day of the earthquake, they said:

> *"Fonterra were here that day [14th November] to see how we were getting on. They didn't help that much because we had things that our advisor had things under control. But they made sure they [the cows] weren't in the road and whatever had to be done. So, they were good, supportive."*

The agricultural organisations (*e.g.,* Beef+Lamb, Fonterra, Federated Farmers) stepped in to support their farmers in a variety of ways immediately after the earthquake. This support maintained throughout the recovery stages.

*4.5.3.2 Short-term (<6 months)*

Community

The community continues to be a source of off-farm resources during the short-term recovery period.

The Farm B farmers worked with one of their neighbours to manage an unrepaired boundary fence through the winter rains (See section 4.4.1.3 for more).

Government

During the first six months, many of the government mandates and aid came into effect.

MPI had an uninsurable assets fund that provided money to farmers who had assets that were not covered under insurance. For many this was tracks and fences. One farmer described how the uninsurables fund helped their financial issues:

*"We've probably spent close to $300,000 of our own money. We did get $100,000 dollars from the government. It initially looked like we were going to get about $45,000 maximum. So, when they subscribed the uninsured infrastructure fund that was undersubscribed. So, you'd think 4 million dollars, but as it turned out there's a small amount of farms with a lot of damage. So, they put a few points of entry into it. So, you had to make a deposit 'cause that would sort of rule out any lifestyle block owners trying to tap into it. You know, they really wanted, from their perspective the money to go to the right place. So, we did a scope of works. I think [Farmer 2] came up with somewhere around 600,000 dollars infrastructure damage, which is uninsured. Which was water, tracks. Repairing land. All that sort of stuff. So, we put that scope in. And then I had a conversation with our local MP and MPI, I wanted to know when they got the information in about the level of damage, what they were going to do about it. If there was a lot more damage than what they'd supplied money for. Were they prepared to front up with any more money?"*

MBIE offered Rawhiti cottages, originally from the 2011 Christchurch Earthquakes, at a discounted price to farmers. The farmers on Farms B and C took advantage of this. Farm B's cottage arrived in April. Farm C's Rawhiti cottage replaced one of the damaged staff houses.

One farmer remarked that some lessons with regards to public engagement had been learned from the Christchurch earthquakes and beneficially applied. There were frequent public meetings in the first few months that helped explain insurance rights and earthquake law. The farmer described these meetings:

*"We had several meetings at the community hall in Waiau that were run by [Insurer], private insurance, council and everybody was there. And they had to stand and talk and people could fire questions at them and they were accountable, all of a sudden. And so, the council was really proactive or Rural Support, whoever it was, at getting every eight weeks or so there was a different stage, so we've had the initial response and now we are at the stage here that's repairing infrastructure, so we had another meeting and we started getting to the rebuild, insurance side. They had people talking that weren't aligned with the parties that you were dealing with, but were experts in the knowledge or the law around that talking to you, so you knew what your rights were. 'Cause it cost us a lot of money to engage with our lawyer, but some haven't got the ability to do that. That community laws been set up that's specialising in earthquakes."*

<u>Contractors, Consultants and Suppliers</u>

The Farm B farmers were able to complete emergency woolshed repairs within the first few weeks. In order to complete their more permanent stockyard and woolshed repairs a consultancy company was hired by insurance to complete the scoping work. The company had Christchurch earthquake experience, but had never done rural work. They were unfamiliar with many farm terms and farm infrastructure requirements. Their experience did not transfer regions. This lack of experience slowed the recovery process because the company had no understanding of what needed to be repaired. One of the farmers commented on a survey company's lack of experience:

*"The sheep yards, for example, lifted 1.6 metres from the back of the yards to the front. They used to run slightly uphill. Sheep naturally like running uphill. For a sheep to run downhill, they just hate it. Don't ask me why, but they don't do it. To try to get a scoping team from Christchurch that have never done any rural work, to try and explain to them that the sheep yards need to be flat or on a slight incline because that's what they were. They look at it and tell you, they've just got no understanding of what it is they're dealing with"*

In a follow up, the farmer noted that the company had a bad reputation.

*"We've since heard that the guys that started, I won't use the company's name, but it won't be hard to find out, that do the scoping for FMG was a failed building company in Christchurch anyway. And I don't even think they employ a structural engineer."*

Employment costs were another issue. One farmer explained why hiring contractors to complete several tasks at one time and accommodating them on farm as cheaper:

*"It's way cheaper to get a contractor to do lots of little jobs, rather than hire for each job. The travel, accommodation and meal allowance for a thirty-week project, which is around building a new home would be 80,000 dollars. So, you could imagine if you take a cash settlement from your insurance company and your painter has done a quote say to spend four days on site and they don't get a bit finished and there'll be a clause in there that if they have to come back and forth, it's around 70 cent a k. Most people are charging around 70 or 80 cents a k...it doesn't take many days of travel to start to ramp things up. And whether they come up for a day or half an hour, you incur the same cost. "*

Non-Governmental Organisations (NGOs)

NGOs stepped in to help in specialised ways following the earthquake. The Queen Elizabeth II (QEII) trust was involved in retiring land that had been damaged by coseismic hazards. The Rural Support Trust expanded their work that had begun during the drought to include advocacy as well.

Before the earthquake, the Farm A farmers had gifted some land to the QEII. QEII acts as a steward for the land gifted to it, but the gifter typically continues to maintain and care for the land. Some of the land that Farm A had gifted turned into a large landslip during the earthquake. It had been mostly returned to its natural state and was covered in Manuka. The earthquakes damaged fencing on the gifted land. QEII had a fund to pay for natural disaster mitigation and repairs. The farmers were able to use this fund to repair the fences on the gifted land rather than having to use several thousand of their own dollars.

Rural Support Trust is an organisation that really imbedded itself in the community during the drought. Its purpose is to provide mental health services to farmers. There are several regional branches. The organisation made its presence felt by simply being around, supplying community get-togethers and even acting as advocates at civic meetings. One farmer described the trusts contributions to the recovery effort:

*Farmer B: "Rural support trust. They had really kicked into gear during the drought. Well after the earthquake, they knew exactly what they were dealing with from stress, whether it was from the drought or earthquake or whatever. I am not aware of anyone around here that committed suicide in the wider Canterbury from the earthquake. From the drought, I better not speak out of turn 'cause there are quite a few farmer suicides every year in New Zealand. Just financial pressure or whatever and I am not aware of anything that's gone on down here. But they've got to take a huge amount of credit for- they were just around. There was beers arriving at people's farms for barbeques. We just need to get everybody together, have a barbeque. If somebody's sitting by themselves who is normally quite friendly and got a bit of attitude with them and all of a sudden, they're looking a bit down and stuff. That's the chance that everybody's got to and they were out there saying there's no disrespect. If you think someone is not right, just get off to say something to one of those rural support people because it's all confidential and behind closed doors and we just go out* *there and make sure they are ok. You are better off to make that phone call rather than…yeah, not do anything. That Rural Support Trust has been amazing. Just linking stuff in people's ears. They are high enough up the chain that giving a bit of trouble with something they can- "*

***Researcher: "Grease the wheels?"***

*Farmer B: "'Cause once a month, once every few weeks, once we got further into it. All the insurers had to report in a three weekly, monthly meeting, whatever that was. MBIE, I think was part of it, MPI, I think was part of that, the council was and so they would say this is case X and there's been a lot of frustration from those people and what's going on? And they'd say we've done this or we've got this in line and all those other organisations knew, like Rural Support Trust, knew exactly what was going on and if someone was not quite putting out what the case was they were caught up with quite quickly and so there was no sort of hiding. Originally, there was people coming into these meetings saying this, this and this have been done and these people are fine and someone was able to sit there and say, well we've been there and that's not the case at all.*

*I was pretty impressed with how everything kicked off around that with the earthquake."*

#### *4.5.3.3 Long-term (>6 months)*

As time passes, outside support recedes. The sudden absence of attention and aid magnifies the stress of recovery. A Farm A farmer commented on this effect:

*"Well you talk about the cascading effects of physical business and stress and physical reactions to things. That in itself is probably the biggest thing I've had to deal with. The anger and the frustration and the turmoil. I think at the start. There is a lot of love around, good will, a lot of help. It's a really good vibe and then it all disappoints. You feel like you're trudging along by yourself."*

Insurance and contractors have the most contact. Some longer-term government and NGO initiatives come into place following lessons learnt from the earthquake.

Government

Most of the government initiatives were enacted soon after the earthquake. Most of the government's interactions with the farms' recovery in the long-term were with this previously discussed initiatives and a return to regular regulation. Later in the year, Farm A also acquired a discount Rawhiti cottages. The cottage arrived on site in December.

Contractors, Consultants and Suppliers

The Farm A farmers hired a lawyer in August 2017 to help them deal with insurance. This was much later in the process that the other farms. They were pushed to hire a lawyer when they realised that they might lose the chance to complete repairs before winter. They commented:

*"And [lawyer]'s just sort of making sure the wording of our insurance means that we are covered for the loss and the land equation of the insurance. So, we are doing a due diligence process with them. In hindsight, I probably should have rung the lawyer within a week…Just put a game plan in place. Just a strategy."*

On Farm B, the farmers encountered issues when reinstating insurance on their repaired buildings and adding insurance for their new buildings. They recommend hiring a lawyer pre-earthquake in order to make sure that farmers have a thorough understanding of their coverage. One farmer described their process of insuring their new structures:

> *"But what we're finding now is we're starting to get the woolshed reinsured and insurance for this house, when we got it on site that you probably really need to get a lawyer or solicitor to read through because they're changing what we had. We're on total replacement for everything here, but everything that's been bought on farm or will be built, which they now consider more risk than what they had has now gone on nominated policy...Since we've got through this, it pays to spend a couple of thousand dollars, five grand for a solicitor to read your policy and actually have a full understanding of what you've got so if you need to tweak them, you do because when an event, or something like this, occurs you rely so much on insurance."*

<u>Agricultural Businesses and Organisations</u>

Federated Farmers and Beef+Lamb, with the support of MPI, have started a series of projects to help with long-term re-planning. MPI originally set up a land-use advisory fund for individual farmers. This fund has transformed into community advisory projects so that consultants can be hired to create issue specific reports. The initiative had not kicked off by the time of the second interview in January of 2018. Committees had been formed and the opinions of the two involved farmers were mixed.

One farmer described what they hoped to gain:

> *"Yeah, well we haven't kicked that off yet. There was a lot of toing and froing about how the money should be spent and what it should be spent on, but that's what been come up with. So, they've split into three groups, the money's been allocated and then of those three big areas they've gone into little subgroups and so instead of paying a consultant to come to each farm. He can come out, 'cause you're going to pay for him for a day and do say three farms or whatever it was, but other people who are involved in that group would learn enough from the reporting that came back to put the ideas-…So, he might do a bit of a report on forestry and bees, which he doesn't need to go onto everyone's farm to do because we know that area might go into trees and we'll leave a bit Manuka there for the bees or even plant some Manuka for the bees. That report will tell us everything from step one through to-. It's put the foundation there for us…."*

Another farmer commented that they would prefer a more practical repair focused fund than the committees:

> *"Yup, so they are trying to get- To me I'm a bit cynical. Fencing is still number one. It's all very well and good walking in and saying you need to do this, this and this. I just don't see why we have to pay people to come and tell us how to suck eggs. Pragmatically, ten grand on wire and Waratahs, fencing standards would definitely be a better use of the money. I think the council was always going to have an advisory role because Environment Canterbury ultimately has a say on how land is managed anyway. So, you could argue that that sort of stuff is already in place. We need pragmatic solutions."*

#### *4.5.3.4 Exogenous Management System*

Exogenous management systems are management systems with a majority of off-farm support components. These may include advisors, ownership boards and financial consultants. They are frequently associated with large off-farm networks. The farmers of Farm C are the only ones of the three sets of farmers to have this management style.

The Farm C farmers had a team consisting of their bank manager, farm advisor and accountant. Their bank manager and farm advisor called on their extensive farm networks to identify and contact dairy farms who were able to take in some of Farm C's cows. The farmers would did not have access to the information about which farm had which kind of dairy shed. They were also not have had everyone's contact information readily available. Without this team they would not have been able to evacuate their dairy cows as quickly and efficiently as they did. Their team knew Farm C's status, assets and dairy shed type and were able to match it to that information for many farms in the region. This collective, network knowledge allowed them to select the farms best suited to take the dairy cows.

One farmer described their team:

> *"...we've got a team. And as I say, we've got our bank manager, our accountant, our advisor and ourselves. The four[?] of us know exactly what is going on on this farm all the time. We don't see the bank manager all the time, but he gets a breakdown of our money pay-outs accounts and that. So, when it has happened that team has worked for us. So, I think that's the main thing to have. You can't say ok I'll build a plan round this disaster, that disaster, you can only react to disaster really. But the plan is to have that strong group round you and that sort of includes insurance too."*

Exogenous management systems' greatest asset is its network capacity. This system works with farms that have a precise day to day plans. It makes up for not being as flexible as a small on-farm team by having a larger human resource pool to draw from.

#### *4.5.3.5 Exogenous Support Summary*

Exogenous support infuses the farm with resources when their on-farm resources are stretched to their limit. Every exogenous entity varies in term of interaction timing and the nature of their support. Coordination between levels and different entities could be improved. Long-term support is lacking. The sudden absence, after much immediate aid at all levels, magnifies stress. Large networks of support save lives. When a farm is isolated by geography or hazards, exogenous support cannot access the farm. Instead the farm must rely on its internal, endogenous, support, which may not be enough. Most exogenous support is economic.

## 4.6 Economic Factors

Economics drive the farm. Without financial resources or the ability to create financial resources, a farm cannot function. The economic decisions a farmer makes pre-earthquake (*i.e.*, buying insurance and setting up an emergency fund) are forms of preparedness that affect their ability to recovery. Exogenous support often comes in financial form (*i.e.*, government grants or NGO donations). Government grants generally apply after the event's scale is known. A farm's immediately accessible economic resources is both their physical assets and their liquid capital. The timeline of when and for what purpose money is made available controls the recovery timeline. This section will focus on the major economic sources: insurance, emergency funds and government grants.

#### *4.6.1.1 Pre-earthquake*

Before an earthquake occurs, farmers can make several financial decisions to increase their capacity to recover. Insurance is the most direct form of financial preparedness. Farm A had business interruption insurance. When they were unable to shear their sheep because of the damage to the woolshed, they were able to enter a claim. The price of the wool decreased due to deterioration tied to not being sheared on time.

A farm's emergency fund is a measure of preparation. The amounts vary between farms. The Farm A farmers' fund was not as large as it might have been because they had just completed a water and fencing infrastructure upgrade. In addition, the damage meant they effectively had to purchase that infrastructure twice.

Like the Farm A farmers, the Farm B farmers had suffered some economic losses due to the earthquake. However, much of their low financial resource pool came from resolving an ownership buyout. One farmer commented on their compounded loans:

> *"'Cause probably we were in the drought and we had to take some loses anyway and all of a sudden, we were talking about a substantial amount of money we had to pay others out and then we had the earthquake. So, we had basically gotten to the point where our borrowings were what we basically considered to be the maximum to still run efficiently on farm."*

Insurance is another form of preparedness. The intricacies of different insurance types are outside the scope of this these. The importance of hiring a lawyer before insurance needed to be used was emphasised.

The Farm C farmers did not have business interruption insurance. Unfortunately, this meant that when their dairy shed was made non-functional, they were left without recourse for their lost income. The farmers discussed this insurance:

> *Farmer C1: "And we should have had business interruption insurance. You know, we had talked about it, but you don't think- But with the dairy shed out, it's not like if you're sheep and beef, you know, the grass still grows. Even if you're flooded or whatever, it's still going to keep growing, but with the dairy shed out, we were totally out of business."*

*Farmer C2: "Worst scenario, you know, yeah the shed might be a bit- but the cows can still go somewhere for a couple of weeks then you get them back and start milking again, but it didn't it was out all season. Had it been at the end of the season, it wouldn't have been too much of a problem, it just hit us right where- "*

*Farmer C1: "Peak."*

*Farmer C2: "And when you're running, it's a reasonable size business, and five grand or whatever for that business interruption, is not going to break the business. But if we don't have it, it could."*

*Farmer C1: "The two sheds either side of us, they were out for one day, they were out for two days and the farm next to them, they carried on milking, so you know it's very extreme for your shed to be a total write off and that's what the insurance have said. Total write offs are usually fires or maybe floods, perhaps, but not like that. So, in hindsight we should have had business interruption, but we have now. We've shut the gate."*

#### *4.6.1.2 Insurance Claim Settlement Processes*

MBIE opened a wage subsidy fund for small business employers to be able to continue to pay their employees. The Farm C farmers were able to take advantage of this fund. It helped fill some of the gap left by not having an income source and business interruption insurance to replace it. Since the earthquake, they have taken out business interruption insurance.

Insurance came into effect immediately. Two of the farmers had spoken with their insurance agents and companies on the day of the earthquake. The third had an on-farm visit within a week. This speed did not last past Christmas. One Farm B farmer described their insurance's early involvement:

*"Yeah and the response from the 14th of November to, I recon, about the 14th of December, for about a month, maybe for a few days after that was…you could not fault it. There was nothing they weren't trying to help with. If we can get that person there to find out what- if you get that done, send us an invoice, but all of a sudden, the rules changed and it went from let's get this working and moving to we need to send out Inovo, which is the company that does the scoping for them."*

A number of lessons about insurance coverage were garnered during this time. One Farm A farmer commented:

*"The insurance for farm houses is geared towards urban water supply, where you've got a supply of water at your gate. And they will cover you for 50 metres or so within your house boundary."*

On the other hand, a Farm B farmer found that some parts of their system were unexpectedly covered under insurance.

*"We've discovered that a water tank comes under an unspecified farm building. For my policy, we could have a claim for 5,000 dollars per unspecified building to a maximum of six claims. So, you could have up to 30,000 dollars. There are things like that that are in your fine print, that to be honest I haven't really read through it, but they triggered."*

In mid-December 2016, the insurer closed a deal with private insurers to manage processing for earthquake claims covered by insurer (EQC 2016). The goal of this agreement was to simply speed the insurance process for claimants. The insurer's earthquake insurance claims window closed mid-February. Most of the claimants have been addressed, but not everything had been resolved as of January 2018. Farm A rejected the insurer's initial offer. The farmer described their experience with the insurer:

> *Farmer A: "This earthquake is a little bit different to the Christchurch earthquake where [Insurer] got the insurance companies to act on their behalf to do all the building assessments and stuff like that. So, [Insurer] haven't been on the coal faces this earthquake. It's been subcontracted to [Insurer] and [Insurer] companies like that. So, [Insurer] when we have dealt with them have been really prompt and on site. The likes of [Neighbour]'s retaining wall and damage to his land. They were very quick about that. And they were quick over there [the shearers' quarters' direction] too, it's just that I think they were wrong. And they will say 'Aw, it's not impending doom' or what's that the term or phrase."*
>
> ***Researcher: "Imminent Risk."***
>
> *Farmer A: "Imminent Risk. And I'm like, 'Aw well doesn't really matter because it's on a fault rupture.' The hazards, they are two different things, but they cover more ground. The landslides giving me the shits more that the fault ruptures. But also, it's just not going to neatly follow that fault and then that fault there. It could be once that bit goes, that bit decides to go as well."*

During the start of the short-term recovery period, insurance companies began to be impacted by the reaction of their reinsurers. A farmer described this transition:

> *"When they were starting to see the size of the event. The reinsurers were starting to get involved and as soon as the reinsurers got involved, all of a sudden, the breaks went on and that was it. 'Ah, no sorry. We can't do that now.' Like, 'We've got so-and-so coming up to fix this, do emergency repairs, not a problem, just send in the invoice when you've got it fixed.' And reinsurers were starting to get some exposure to it and all of a sudden, it's like there's no more of that. You have to be assessed by [Surveying Company] was the company that they used. They have to come up and assess it and there's all this reporting that has to go through before anything would be. And so even your assessor you'd ring him up, that was on your case, and say 'We're at a point where we fix this to keep going.' And he'd just say, 'My hands are tied. I'm not allowed to do anything unless scoping team signs off on it.'"*

Insurance claim resolution is a gradual process. Claims for infrastructure covered under the same policy may be settled at different rates.

The extended process allows for more opportunities for slowing the process further as new people are brought in. One Farm A farmer discussed slowdown:

> *Farmer A: "We've had a number of staff members from [Insurer] leave or move on. We had our own broker leaver her job. We haven't actually dealt with one person all the way through. That's quite frustrating because you feel as though you're actually making some progress and then they leave. They go on holiday. I guess it's the human factor that people's lives change and you can't expect people to keep a job just because your insurance claim is-. But it just creates- there is still a lot of pragmatic conversations that are had and I guess they form positions that they generally sway either way on. And when they start to sway a certain way they act quite quickly. But they seemed to be going back to these new people that all of a sudden they've got to get a heads up."*
>
> ***Researcher: "You're potentially educating a new person?"***
>
> *Farmer A: "Yeah, it feels like that."*

On Farm B, the farmers had nearly a year long argument with their insurers over the coverage and payment of their policies on their woolshed and homestead. Their woolshed claim was settled by April. A major part of their insurance claim struggle was over the coverage of the woolshed's power source. There was disagreement about whether or not the land damage that made the power unusable was covered by insurance. Also. The repair estimates from the insurance company's scoping company and insurance company themselves were not matching. Once the insurance claim settled, the power companies were quick to fix the line.

Farm B's homestead claim took longer. The homestead was not uninhabitable due to damaged sustained, but because a large historic landslide was declared an imminent risk. The local council had refused to issue a building consent for repairs. Numerous surveying companies had surveyed and written up reports declaring imminent risk. The insurance continued to offer repair in the same place. The farmer described the back and forth between various engineering companies, geologists, insurance and the council:

> *"So, we had all these reports back and in the meantime, to get [Engineering Consultant 1] to come back we had, [UC geologist] had put us in contact with [Engineering Consultant 2] and we had a guy that we were working with there that, his name slipped off the top of my head. But anyway, [UC geologist] had said to us, [Engineering Geologist]. They said to us, 'Look we'll put you in touch with this guy and we'll get things rolling. So, we had another report that came back from [Engineering Consultant 2] before the last [Engineering Consultant 1] one that said, 'No, we believe there is imminent risk.' So, as soon as we sent that into [Insurer] they started to really get things rolling and that's when they got [Engineering Consultant 1] back. And there was obviously a lot of stuff going on because that's when that [Engineering Geologist] came out and said, 'Well, yeah.' So, in the end we had two reports. We had the original [The Government Department] one that said not to go into the area. Then we had the [Engineering Consultant 2]'s one that said Nah. They had to state that there was imminent risk, which they did. And then we had [Engineering Consultant 1] come back up under [Insurer] and said yup this is imminent risk. So, we had all these reports and they all went to the private insurer 'cause by this time they were saying Ah yeah send them in send them in 'cause this will help us with our findings, so we sent them all in and the offer came back exactly the same. They said no we don't believe there's any risk. So, we will repair you in the same location. In the meantime, the council won't give a consent for repairs because you have a building consent it has to have a fifty-year lifespan and no one would put their name on a document to say we believe that if we repair this house on this location that for the next fifty years someone will be safe in that location. Because as [UC geologist] had pointed out quite often you'll get these big ruptures and I think he used the Napier earthquake as the prime location. They had a massive rupture come down, was it twenty years, quite a long period after they had a massive landslide come down. And that was a result of that earthquake, it was quite a long time. No one could come up there and say this moment, next month, it depends on weather conditions. So, we get another aftershock… "*

Their claims were settled in November 2017. They credit their lawyers with being a major force in reaching a satisfactory resolution.

#### *4.6.1.3 Long-term Economic Re-planning*

Post-earthquake recovery, there are several changes to the farmers' economic situations, specifically in terms of insurance. To begin with, some of the insurance claims settlement processes stretched to over a year.

The Farm B farmers finally settled with their insurance company in November 2017 after meeting with the head of the insurance company.

*"So, the biggest change we had from mid-August, when you were here to when we actually settled with them was that the head of [Insurer 1] came on site. He was bought up by an independent third party 'cause there were two families in exactly the same situation. Us and another family up the road. Both with a house at the base of a hill. Both with exactly the same situation. Both fighting and arguing with the insurance company and getting nowhere. So, in the end a third party, once again a door was opened by someone else for a third party who knew how to link everything together, got the head of [Insurer 1] up and he came and sat and met with us and actually listened. Did both families on the same day. He came to us second. And listened and I had no idea what had gone on in the other meeting and what we were telling him mirrored exactly what the other family had gone through. Whether he knew or not, he just apologised and said, 'What I've been getting down from my staff is completely different to what you guys have just told me. So, we had the head of the earthquake recovery for Kaikōura, which was [Insurer 1 Employee] who used to work for [Insurer 2] who was head hunted or whatever, snapped up by [Insurer 1] 'cause of experience, was removed from our case that day. So, we'd been arguing with him for months. And we'd get some really smart. Even our lawyer, we ended up litigating through the litigation side of our legal team because our lawyers got so fed up with his bullshit. He was just the smartest...As soon as we outlined everything that was happening, he was removed from that point. And everything started to roll quite quickly. I kept saying it was funny, everyone was battling with [Insurer 2], [Insurer 1 Employee] was in charge of the bloody thing. And as soon as he leaves, all of a sudden, you start getting good stories about [Insurer 2]. And we've had no problems with [Insurer 1] and the minute he took up office in [Insurer 1]. We broke up for Christmas, as soon as they started back, I'd say properly because your insurance agency never shuts down, but once that mid-January period rolled 'round he was in charge and that was when everything started getting sticky."*

The Farm C farmers commented that insurance companies had to learn how to process earthquake claims. Insurer and the private insurance companies had come to a claims processing agreement shortly after the November 14th earthquakes. The farmers were impressed by their insurance company's adaption:

*"I think the insurance have come a long way since then too. You sort of have to appreciate where they are to the Earthquake Commission when they put it all together 'cause our insurance joker said we don't know what we are doing because we haven't dealt with that part before. And yet they were handed that over. Since then they've gotten a couple of chaps from the earthquake commission team. But there was a lot of work for them to do to get up and running as to what they needed to do and how they dealt with it. 'Cause it's like everything. It's always changing, isn't it? 'Cause you think you're set up right, that earthquake came along, bam, how do we deal with the commission? Set up there, how's it going to work? We've got the team, have we got enough people?"*

By January 2018, the Farm A farmers had put a halt to repairing any more of their water system until an insurance claim they had put in for it came through. Their water was functional, but not ideal at this time.

A Farm B farmer hoped for the chance to give their insurance feedback:

*Farmer B: "And I would hope that they would ring me and actually sit down with me to say, you've gone from the earthquake, now you've been settled. Probably got a pretty good idea of what they thought our experience was, but sit down and actually work out what the short comings were. I think they need to visit their clients and work that out. They can do it internally, but they've got to speak to the people-"*

***Researcher: "Decent debrief type thing?"***

*Farmer B: "Yeah"*

In addition, post-earthquake the farms' insurance policies are being updated. The Farm B farmers are finding that the earthquake has changed their policies completely. They explain that their coverage type changed:

*"But what we're finding now is we're starting to get the woolshed reinsured and insurance for this house, when we got it on site that you probably really need to get a lawyer or solicitor to read through because*

*they're changing what we had. We're on total replacement for everything here, but everything that's been bought on farm or will be built, which they now consider more risk than what they had has now gone on nominated policy."*

They found that the nominated policy offers were not close to the values they had anticipated. They discussed the frustrating difference between nominated and total replacement coverage. Some of their neighbours found that following the Christchurch 2011 earthquakes, the insurance wording had changed. The farmer explained the confusing disaster-related insurance changes:

*"With the nominated their saying that 'Well if you can get someone to come up and replicate what you had, in terms of damage, we'll rebuild it's a total loss. If we think we can do it for less than your nominated value, we'll manage the project.' I'm better to be slightly over insured because I'm the one paying the premium. If you think you can fix it or reinstate it for less than the amount that I've insured it for, to me that doesn't matter because if you're putting back like for like what difference does it make? But if I only insure at your value and then the woolshed burnt downed and someone came up to do a quote to rebuild it and they said it was half a mil and I'm only insured for 300, I've got to find 200,000 dollars. Because at that point they say, 'Aw, we're going to cash settle you' I bet you they don't say 'we're going to manage the project' because they know they can't reinstate if for the money they've got on the-. I know of people, the guy that works for me even, who have got some insured. Just round numbers again we'll just say half a mil and then in their policy fine prints they've discovered that since Christchurch it's been changed now under an earthquake or a natural disaster, even though you have some insured for that amount, we send valuers back in and if we think that the house is worth less or the value of things is worth less than the sum insured we're going to pay you out the lesser of the two amounts. And so, a lot people are saying, 'well hang on. We've actually asked you what you think we should reinsure our house for and they've said half a million dollars or that half mil marker, whatever sort of house you've got. 'Cause that's what it is to replace. But now you're saying that you'll send someone in and if they say that it's an old house and it's only worth 300. Cause you can't rebuild something for that."*

Ultimately, the farmer recommended involving a lawyer to aid coverage understanding and prevent issues before insurance was needed. They said:

*"Since we've got through this, it pays to spend a couple of thousand dollars, five grand for a solicitor to read your policy and actually have a full understanding of what you've got so if you need to tweak them, you do because when an event, or something like this, occurs you rely so much on insurance."*

As contrast the Farm C farmers have experienced only minor changes. Their insurance premiums increased. Nothing changed outside their expectations.

#### *4.6.1.4 Economic Summary*

A farm cannot pay the recovery bills required to return to full functionality from their own capital resources alone. Insurance and government grants are vital for farms to be able to complete repairs within a reasonable period of time and maintain functionality. Legal advice is essential to help farmer understand the extent of their coverage before needing to place a claim. Post-earthquake legal advice for dealing with insurance was advised as well. Several issues arose in connection with the insurance process. Given the new policy of having the private insurance companies subcontract for insurer and the magnitude of the event, it would be prude for insurance companies to conduct post-event debriefs of their own. Pragmatic focused grants (*i.e.* paying for uninsurable infrastructure such as fences and water) was viewed more favourably than advisory grants.

## 4.7 Impact and Recovery Timeline

Earthquake impact and recovery happens over three stages: initial response, short-term recovery and long-term re-planning (Figure 10). A close examination of the timelines of each case study shows similarities at the larger scale (*i.e.* regional) and differences at the smaller scale (*i.e.* farm). Although, all three farms experience the three stages of recovery, their timing and transitions are different.

Stages of Recovery

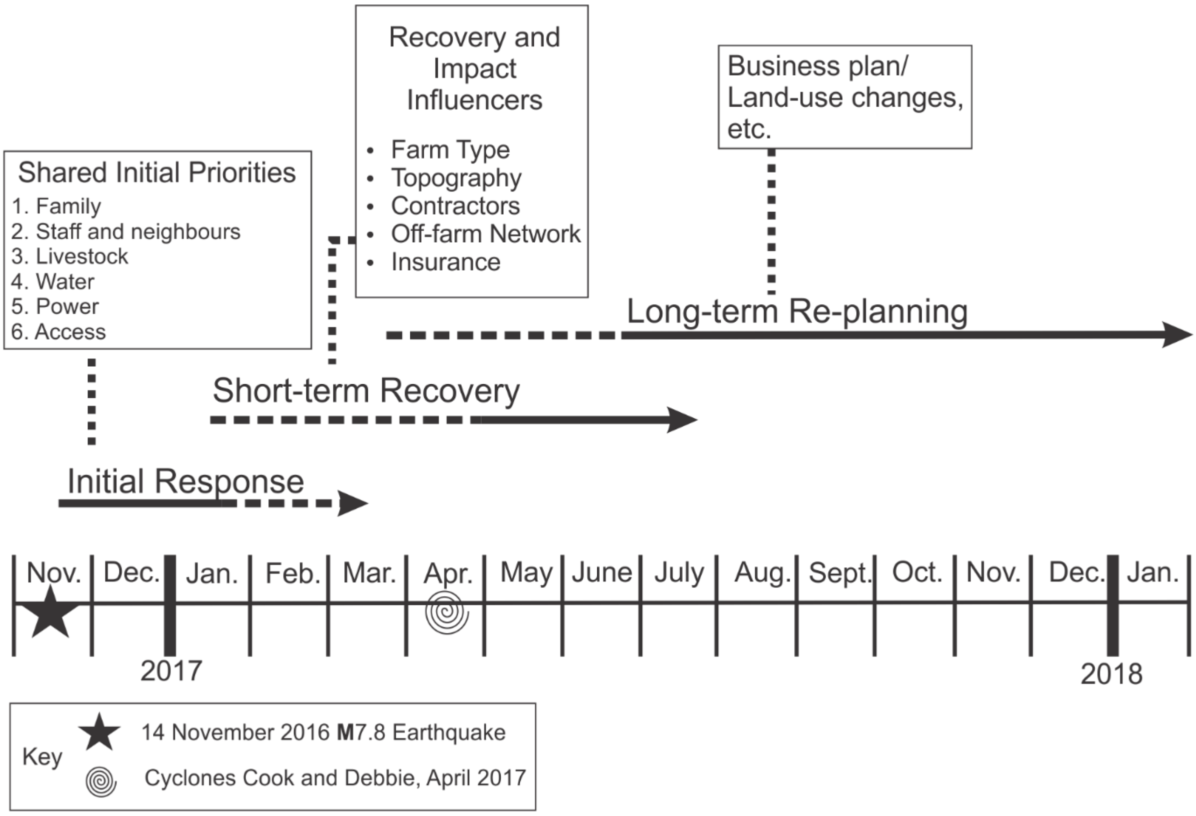



*Figure 19 The three broad stages of post-earthquake recovery are initial response (approx. the first six weeks to three months), short-term recovery (approx. first six to eight months.), long-term re-planning (may span years). The transitions between each stage are gradual. The length and timing of each stage differs between farms. Significant events marked are: 14th November 2016 earthquake (star) and April 2017 cyclones Cook and Debbie (spiral).*

### 4.7.1 Response and Early Recovery

The initial response to the earthquake lasts approximately 6 weeks to three months. The farm level priorities are similar across all farm: life safety and lifeline restoration. Most repairs done during this time are emergency repair designed to restore basic function to the farm. Farm A's initial response stage lasted slightly longer due to on-going water restoration issues. Slow contractor work and cascading hazards (in the form an overtopped landslide dam) re-damaged their water system.

Short-term recovery is from approximately six weeks to eight months after the earthquake. The basic priorities have been achieved. Repair shifts from emergency to permanent. The April cyclones and winter rains stretched out repair by undoing repair work during this time. Farm type (*e.g.,* dairy, sheep and beef), topography, contractors, off-farm networks and insurance are main influencers to the speed and prioritisation of tasks during this stage. Each farm type has different infrastructure and resources. The farms with more variable topography displayed more cascading hazards that re-damaged infrastructure. Pre-existing relationships with contractors can be beneficial. High demand for contractors decreases workforce availability, which slows individual farm recovery. Strong off-farm networks can be another workforce and experience resource during this time. The insurance process enters high gear during this stage. During the initial response stage, most of the insurance process was submitted claims, conducting surveys and returning initial estimates were the bulk of the initial response stage. The major claims began to be resolved and paid out during the short-term recovery stage as permanent repairs began.

### 4.7.2 Long-term Re-planning

Long-term re-planning spans years. It typically begins after permanent repair of major infrastructure is complete. However, if rebuilding is delayed or the farmers are considering a major change in direction, re-planning can begin much sooner. During this stage farmers may adopt a conservative, expansionary or mixed approach to plan the future of their farm. Repair of water pipes and fences continue. Cascading hazards triggered by the earthquake continue to re-damage the farm.

### 4.7.3 Case Study Timelines

The case study timelines were divided by spatial and temporal scale to demonstrate the variations on those scales (Table 11, Table 12 Table 13). At the district and national levels, the key events for each farm are nearly identical. The only variation are initiatives that only impacted certain farms. For example, the MBIE's wage subsidy for small business employers used by the Farm C farmers. Also, only the Farm A and B farmers have participated with the land-use advisory committees because they have had more significant land-use issues that the low relief dairy farm. All three continue, and anticipate continuing, having to conduct water pipe and fence repair.

<u>Key variations at the farm level:</u>

- The Farm A farmers did not receive major insurance claim resolution within the first twelve months.
- Farm A's pump shed was re-damaged by landslide dam overtopping. A smaller, unstable landslide dam-related lake continued to damage fences for several months.
- Farm B's homestead was the only main homestead lost due to coseismic hazard related risk.
- Farm B had power and water restored at the farm-scale during the first few weeks. It was not restored until April (power) and May (water).
- The CDEM roadblock only impacted Farms A and B, of the three.
- Farm C's primary economic infrastructure complex (*i.e.* dairy shed) was repaired within eight months of the earthquake.
- Most of Farm C's livestock (1000 dairy cattle) were evacuated within the first forty-eight hours. This left the farmers unable to use their main revenue stream until the end of July (eight months later) when the cattle had been returned and the dairy shed rebuilt.

Insurance, farm type and geographical location are the main factors in the key farm level variations.

*Table 11 Farm A's earthquake impacts and recovery timeline. The timeline is displayed on two intersecting scale (spatial and temporal). The yellow boxes refer to asset acquisition, rebuild or repair. The green boxes contain financial input events. The pink boxes refer to financial grant announcement or process engagement.*

Farm A

| | | TEMPORAL | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Pre-Event | Immediate (1 week) | Immediate (6 weeks) | Short-term (3 months) | Short term (6 months) | Long-term (<12 months) | Long-term (>12 months) |
| SPATIAL | Sub-farm | | | | | | | |
| | Primary Economic Infrastructure | Woolshed build near river valley edge. | Woolshed damaged. Landslides form near woolshed. | Neighbour's woolshed used to finish tailing. | | | | |
| | Homestead | Homestead constructed near primary infrastructure. | Sewage system damaged. | | | | Sewage system problems worsen in winter rains. | |
| | Other Infrastructure (e.g. fences) | Stockyards, storage facilities and other major buildings centralised to flat section of land. 300K upgrade of fencing and water system. | Power, water, telecommunication and transportations damaged and disrupted. Surface rupture goes through shearers' quarters and makes it uninhabitable. Landslide dam blocks river and destroy water shed. Insurance engaged. | Power (3 weeks) restored. Fence, road/ track and paddock repairs begin. | Water (2 months) restored | Water, power, track and fence repairs on-going. | Water, power, track and fence repairs on-going. | Water, power, track and fence repairs on-going. |
| | Farm | Three-year drought. Stock number decrease. Took out business interruption insurance. | Helicopter survey supplied by Beef+Lamb | | Landslide dam bursts and re-damages water system, fences and flood gates. | Landslide dam bursts and re-damages water system, fences and flood gates. Uninsurable fund decisions returned (end of March). | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Neighbourhood | | Main off-road access damaged. Roadblock put in place. | Roadblock ends. | | | | Still need to settle insurance claims. |
| | District | | State of local emergency declared by Mayor Winton Dalley. Water restored to Waiau within two days. | | | Hurunui Mayoral Hardship Fund Hurunui EQ Community Team formed (May) | | |
| | National | Resource Management Act 1991 Building Code 1992 Building Act 2004 | MCDEM activated and declares state of emergency. MPI announces 5 million dollar primary support package. | MPI uninsurables fund. Private Insurance and EQC agreement simplified process. Special lotto wellbeing fund. MPI $4 million fund for uninsurables. NCTIR formed. $3 million natural hazard monitoring funding increase. Hurunui/Kaikōura Earthquakes Emergency Relief Bill (December) | | EQC applications due (mid-February/ 3 months after earthquake). Cyclones Debbie and Cook (April). | End of legislation allowing for earthquake recovery repairs to commence on private land without pre-approval (July). $2.61 million to Kaikōura/ Hurunui fix waste depositories/ systems, etc. | Cyclone Gita. MPI consultant community projects starts |

*Table 12 Farm B's earthquake impacts and recovery timeline. The timeline is displayed on two intersecting scale (spatial and temporal). The yellow boxes refer to asset acquisition, rebuild or repair. The green boxes contain financial input events. The pink boxes refer to financial grant announcement or process engagement.*

Farm B

| | | TEMPORAL | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Pre-Event | Immediate (1 week) | Immediate (6 weeks) | Short-term (3 months) | Short term (6 months) | Long-term (<12 months) | Long-term (>12 months) |
| SPATIAL | Sub-farm | | | | | | | |
| | Primary Economic Infrastructure | | Surface rupture next to woolshed damages woolshed and disrupted power. | | | Power (April) and water (May) restored to woolshed. Woolshed repaired. | | |
| | Homestead | Homestead constructed beside a hill with historic landslides. | Moved into caravan. | | Farmer's family moves off-farm. | Farmer and family move into Rawhiti cottage purchased from MBIE (April/ May). Farmer and family move into constructed shed-house (October). | | Plan to build second homestead. |
| | Other Infrastructure (e.g. fences) | Three stockyards were constructed across the farm. A second water system was built on the back part of the farm during the drought. | Water, power, fencing and stockyards damaged. | Most stock pipes repaired. Emergency stockyard repairs for weaning pre-Christmas. | | | Stockyard repairs complete (June). Water scheme completely refilled (July) | |
| | Farm | Three-year drought. | Insurance engaged. | Crops drilled. Historic landslide moves, fractures widen. | EQC applications due (mid-February/ 3 months after earthquake). Historic landslide moves, fractures widen. | Uninsurable fund decisions returned (end of March). Historic landslide moves, fractures widen. | Insurance settled (November). Historic landslide moves, fractures widen. | Plan to hire a full-time employee. Historic landslide moves, fractures widen. |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Neighbourhood | Cell tower installed in Waiau | Main off-road access damaged. Roadblock put in place. | Roadblock ends. | | | | |
| | District | | State of local emergency declared by Mayor Winton Dalley. Water restored to Waiau within two days. | | | Hurunui Mayoral Hardship Fund Hurunui EQ Community Team formed (May) | | |
| | National | Resource Management Act 1991 Building Code 1992 Building Act 2004 | MCDEM activated and declares state of emergency. MPI announces 5 million dollar primary support package. | MPI $4 million fund for uninsurables. NCTIR formed. $3 million natural hazard monitoring funding increase. Hurunui/Kaikōura Earthquakes Emergency Relief Bill (December) | | EQC applications due (mid-February/ 3 months after earthquake). Cyclones Debbie and Cook (April). | End of legislation allowing for earthquake recovery repairs to commence on private land without pre-approval (July). $2.61 million to Kaikōura/ Hurunui fix waste depositories/ systems, etc. | Cyclone Gita. MPI consultant community projects starts |

*Table 13 Farm C's earthquake impacts and recovery timeline. The timeline is displayed on two intersecting scale (spatial and temporal). The yellow boxes refer to asset acquisition, rebuild or repair. The green boxes contain financial input events. The pink boxes refer to financial grant announcement or process engagement.*

Farm C

| | | TEMPORAL | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Pre-Event | Immediate (1 week) | Immediate (6 weeks) | Short-term (3 months) | Short term (6 months) | Long-term (<12 months) | Long-term (>12 months) |
| SPATIAL | Sub-farm | | | | | | | |
| | Primary Economic Infrastructure | Dairy shed was constructed near a large river. | Dairy shed damaged to the point of irreparable. | | Dairy shed removed. Dairy shed damage payout received. | Dairy shed reconstructed. | | |
| | Homestead | New homestead was constructed on a river terrace set back from the river. | Superficial damage. Some contents damage. | | | | | |
| | Other Infrastructure (e.g. fences) | Old homestead on the same terrace as the dairy shed retained as manager's house. Woolshed retained as woolshed. Sheep fences switched for cattle. Land divided into milking platform and runoff. Irrigation installed across milking platform (rotorainer, k-lines, pivots). Purchased large generator. | Three staff houses damaged. Internal fencing damage. Runoff troughs damaged. Irrigation infrastructure, water and power damaged. Sewage systems come up out of ground. Power restored in 4 days. | Irrigation and water pipes repaired. | | | | Pipe and fencing repair on-going. Staff house insurance and rebuild/ repairs within next year. |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Farm | Switched from sheep to dairy cows in 2008. Did not take out business interruption insurance. | Advisory team (Farm Advisor, Banker, Accountant) activated. 1000 dairy cows shipped to neighbouring farms in North Canterbury. Insurance arrives. | Most employees let go. | | Uninsurable fund decisions returned (end of March)<br>1000 cows returned (starting in April). Rawhiti cottage installed. Hired staff. | | |
| | Neighbourhood | Cell tower installed in Waiau | | Main off-farm road access repaired. Community flood project repaired. | | | | |
| | District | | Minister Brownlee/ Minster Guy visit Hurunui District | | | Hurunui Mayoral Hardship Fund<br>Hurunui EQ Community Team formed (May) | | |
| | National | Resource Management Act 1991<br>Building Code 1992<br>Building Act 2004 | MBIE announces wage subsidy for small business owners. MPI announces 5 million dollar primary support package. | MPI $4 million fund for uninsurables. NCTIR formed. $3 million natural hazard monitoring funding increase. Hurunui/Kaikōura Earthquakes Emergency Relief Bill (December) | | EQC applications due (mid-February/ 3 months after earthquake).<br>Cyclones Debbie and Cook (April). | End of legislation allowing for earthquake recovery repairs to commence on private land without pre-approval (July). $2.61 million to Kaikōura/ Hurunui fix waste depositories/ systems, etc. | Cyclone Gita |

## 4.8 Future

The future of the farm is the goal of the final stage of earthquake recovery. A combination of long-term goals, plans and the responsibility for the next generation factor into the decisions made. Farmers display a variety of attitudes to the results of the earthquake. Some convert to more conservative mind-sets to try and limit their exposure in the future. Others take the opportunity to expand and diversify their economic sources. All three farms changed their business plans slightly. The Farm A farmers developed a conservative farming approach during the three drought that preceded the earthquake. They have maintained this approach but are focusing on and expanding their current ventures. For example, they are going to train and begin caring for their own bees rather than just working with beekeepers. The Farms B and C farmers all discussed more optimistic driven expansion of their farms.

#### *4.8.1.1 The Next Generation*

The farmers on all three farms are parents. They intend to pass their farm onto their children in the future. Many of their decisions regarding the future revolve around making sure the farm is better for their children. One farmer commented:

> *"Farming's intergenerational…There's not many of us who would pass something on in worse condition or not have an eye on the future. Cause what have we done for our children and our grandchildren, nothing. We've got to be sustainable."*

#### *4.8.1.2 Conservatism*

The conservative approach is used to try and maintain the assets and function the farm still has. This can mean reducing stock numbers. The farmers reduced Farm A's stock numbers during the drought as well due to financial pressure. This practice has continued because the weather has continued to be dry. Also, the earthquake made the physical task of controlling sheep more difficult because of the extensive fencing damage.

#### *4.8.1.3 Diversification/Expansion*

The diversification or expansion approach involve exploring new or expanding existing aspects of the farm. For Farm B the earthquake has prompted the farmers to reassess:

> *"There could be opportunities for bees or pine forestry or whatever that I wouldn't have thought of or I just wasn't interested in. I was quite happy doing what we were doing."*

Farm A had bees on-farm pre-earthquake. The farmers contracted with local beekeepers. They are looking to expand into owning their own bees. One Farm A farmer commented the following:

> *"We have decided that we see beekeeping as a future here. We've bought some hives. [Farmer] is doing some training. 'Cause it just changes the risk profile because bees don't need infrastructure. I think beekeeping has a massive future. I just think anything to do with real food and nature operating in a system has got to be good to be involved it."*

Land-use changes also falls under this approach. A large section of Farm A's property lost its grazing productivity capacity due to landsliding. The farmers had retired land pre-earthquake by gifting it to QEII (Section 4.5.3.2 ). They may consider retiring some earthquake damaged land. The retired land was returned to native bush and fed back into their expanded bee enterprise.

The Farm A and B farmers discussed modifying their infrastructure to reduce risk and increase resilience.

The Farm A farmers had adjusted their fencing to reduce risk from landsliding:

> *"We are sort of developing a farming system that is extensive, there's always going to be risk but we are trying to lessen the risk to our infrastructure. Even when we're planning our fences now. I think that's been the thing with this earthquake, which has been a bit of a curve ball. Normally, if you stick to the crest of slopes you are getting out of the landsliding area, but in some places the whole tops of the hills have pulled off, which is just hard luck, but in general we are reinstating. Fences that used to be on slopes we are now pulling them out and we are reinstating them on ridges. 'Cause now that my brain is hardwired to look at landslides."*

Farm B is the only one of the three that uses the county water scheme. The farmers planned to increase water resilience. Their aim is to become more self-sufficient. One farmer said:

> *"The next step will be, even though the drought there were still springs, there was ground that was still spongey. The next stage is digging into those or tapping into those because for stock water, we don't need a consent to tap into them to feed them, but if we can get those. It's probably not going to be as pure as the water that comes out of the river, but if we can have those to either be a backup or split the line because the stock water- well the county scheme water is of the quality we can drink it so it's what we drink and that comes through the tanks and feeds the troughs on the way through. If you start putting springs into those, that water will eventually end up at the house, so if it's clean spring water, it doesn't matter, but it's got a bit of parpara or something you'll pick that up in the taste of it. But I think the next step is making sure we are resilient enough that if we get an event, like a drought or this earthquake or whatever it might come, you've actually got something that can deliver water, you're not relying on someone else to get it to you."*

The Farm C farmers said that the post-earthquake recovery as an opportunity to reassess:

> *"One thing out of this, which isn't quite answering you, but our business model there, has given us an opportunity to really look at it. And we won't be going exactly the same tram lines, we'll be going back a different way and we're looking at it and how we can, given this opportunity. We've had an opportunity to turn over staff that might not have been ideally suited for where they were. So, we got that opportunity to get them right and the business itself a good time to really you got to take the positives out of it. And it's given us a positive as far as really looking at what we are doing. And we are up and running now and shortly we will start having a meeting or two with our advisors and all that and just see where we can."*

#### *4.8.1.4 Future Thoughts*

A Farm A farmer on the future:

> *"I just think it's the sheer scale of it. The reality is that I will probably be dealing with it, this earthquake, for a lot of my life and it always seems to come back to the landsliding that has happened on this farm. As things lubricate and we are talking about massive chunks that in ten years just might have enough whatever they need to move again. So, I think I will be dealing with it for my career."*

A Farm C farmer on the future:

> *"And then summing up like [Farmer] said, we personally are worse off, as of a result of the earthquake, financially, but the farm, like for our boys they'll inherit a better asset. We've got a new dairy shed, a better dairy shed. We will have one new house. That house was sixty, nearly seventy years old. So, we will have a new house. And it looks like we might get another new house that was forty years old. And we've got a better model. We think we've got a much better model of how our business should run. So, in five years' time, I think, we will look back and see the farm is in a much better position. But us personally, we've suffered financially. Like we're getting old and [Farmer]'s working harder than [they] ever has. And we'd like to travel at this stage of our lives, but we can't leave the property because there is just so much going on and still to go on. Our boys will inherit- the mortgages will have a few extra zeros on the end, but that probably won't even worry them."*

#### *4.8.1.5 Future Summary*

The 14$^{th}$ November 2016 earthquake presented an opportunity for all three farms to reassess their situations. The farmers adopted a mixed of conservative and expansionist approaches aimed at reducing risk and increasing their economic profile. All three farmers were made more risk aware by the earthquake. Regardless of their future plans, they all share the same goal of maintaining their farm for their children.

## 4.9 Conclusions

Lessons and recommendations for future farm level resilience and rural area earthquake preparedness have been developed from the five major themes. They touch on every aspect of earthquake impact and recovery.

- Pre-existing conditions:
    - Pre-earthquake farmers and rural areas should conduct surveys to identify earthquake proneness and potential resources. The plans developed from these surveys should take on-going and seasonal climate conditions into account.
- Farmer Experience:
    - Multiple types of farm and community experience contributes to resilience and recovery decisions.

- Physical Impacts:
    - Cascading hazards must be considered for future planning. Reactivated and cascade triggered hazards can cause more damage than the original earthquake and undo months and thousands of dollars of repairs.
- Essential Infrastructure:
    - Infrastructure repair priority varies depending of farm type.
    - A strong neighbour/community/industry network to rely on when infrastructure is damaged or destroyed, reduces impact severity.
- Essential Services:
    - Built-in redundancy and backup system components (*e.g.,* generators, pump repair parts, track access to tanks) speeds recovery.
- Livestock:
    - Every livestock type has different vulnerabilities. Changing or diversifying stock classes may reduce overall impact.
- Mental Health:
    - The recovery process is a cumulative source of stress. There are multiple sources of stress and multiple avenues of support opportunities (*e.g.,* community activities, advocacy, and restoration of home safety).
- Endogenous:
    - On-farm human resources more vulnerable that exogenous support, but essential to day to day flexibility and operation. Cultivating on-farm human resources, if possible may help recovery.
- Exogenous:
    - Off-farm human resources are less flexible and more specialised than endo support, but their large networks can complete tasks that endo support does not have the resources or energy to perform.
- Economic Factors:

    - Farmer emergency funds, insurance and government aid are the three main sources of post-earthquake recovery finance. Involving a lawyer early in the insurance and government aid process eases the process.
- Future:
    - In order for the farm to be functional for the farmers' children, which is the ultimate goal, adjustments must be made. This may mean conservatism or expansion. An earthquake is an opportunity to reassess the plan.
- Timelines:
    - Impact and recovery timelines vary at the smaller scale for each farm due to farm type, resource use (finance in particular) and on-going hazards.

# Chapter 5 Conclusions, Recommendations and Further Work

## 5.1 Thesis scope and methodology

The purpose of this study was to develop several case studies of the Hurunui/Kaikōura earthquake impact to and recovery of farms. The **M**7.8 Hurunui/Kaikōura earthquake occurred at 12:02 am on the 14th November 2016. The earthquake triggered widespread landsliding, rockfall, liquefaction and extensive surface ruptures throughout the North Canterbury and Marlborough region. In addition, the lower part of the North Island, in particular the City of Wellington, was subject to damage from strong earthquake shaking. The Hurunui District is predominantly farmland and was significantly impacted by the earthquakes. To date there have been few farm level earthquake impacts studies in New Zealand and globally.

This gap in global knowledge means that urban earthquake recovery strategies are sometimes misapplied to recovery in rural areas with less than optimal results. A general inductive approach analysis was conducted to identify key factors influencing the impacts to and recovery of farms from the 14th November earthquake.

Timelines and key impact and recovery factors for the three case study farms were developed from the interview responses. A literature review of previous farm-scale hazard impact studies *(e.g., Almond et al. 2010; Craig et al. 2016a; Craig et al. 2016b; Farmar-Bowers & Lane 2009; Whitman et al. 2013)* were used to help inform the semi-structured interview question and factors.

## 5.2 Conclusion Summary

Several conclusions can be drawn from analysing the three case study farms and previous literature. Although the earthquake significantly impacted all three farms, the impacts and recovery timelines were different. The farms encompass the spectrum of farming in North Canterbury, which is mostly a livestock-arable mix (Statistics New Zealand 2013a). The recovery timeline for the three farms followed the same general pattern. Difference sprung from a number of factors, including farm type, pre-existing conditions (*e.g.,* drought) and insurance. Outside assistance was vital to survival of all three farms. However, there were several cases of less than optimal assistance procedure by some groups. Existing earthquake recovery strategies should be updated to properly address farm-scale and rural area needs. The case studies also showed that there are preparedness and recovery strategies that farmers can enact on their own to reduce stress and speed recovery.

Most factors that influence the geological aspects of earthquake hazards on farms are beyond the farmer's direct control or require major restructuring. Key amongst these are farm type, geographical location, climate and time of year. Whitman *et al.* (2013) found from an analysis of urban studies that "*vulnerabilities stem from factors that are often sector specific and geographically driven*." This holds true for the case study farms. The case study dairy farm's initial impacts were the most severe of the three because of the damage to their dairy shed. All three farms' primary economic infrastructure buildings were disabled or permanently destroyed. The higher impact severity was due to the high daily reliance on the dairy shed compared to seasonal woolshed usage. The hazards varied between locations based on topography, and rock and soil type. The on-going climate conditions also changed hazard probability. For example, the North Canterbury drought contributed to decreased soil moisture and consequently decreased landslide probability. The time of year that the earthquake occurred also influenced its impact. Not only because of the seasonal climate variations, but also because the impacts of farm calendar disruption and resource availability varies year-round.

Most earthquake resilience came in the form of earthquake preparedness. This included a variety of forms: insurance, back-up systems and strong off- and on-farm networks. One farmer recommended hiring a lawyer to develop a thorough understanding of insurance coverage before it needed to be used. Misunderstanding or undercoverage increased stress and limited recovery options. Building in essential service and infrastructure redundancies was shown to decrease the overall impacts and increase recovery options. Power generators and equipment, such as diggers, also sped up recovery. Human resource networks were the most vital recovery resource, particularly during the initial response phrase.

Three stages of post-earthquake farm recovery were identified: initial response, short-term repair, and long-term re-planning. The duration of each of these stages was different for each farm. The transitions between each of these stages were gradual. During the initial response stage, the priorities are similar to those in urban areas: life safety (humans and livestock), lifeline restoration and emergency infrastructure repair.

During the short-term repair stage insurance, government aid and permanent essential farm repairs became the focus as the immediate post-event situation stabilised. The final stage, long-term re-planning, may last a number of years.

Farm type, and the inherent aspects of each type, were the main influencers on the lengths and timings of the recovery stages. This is because repair priorities and resources varied. The extensive off-farm network inherent in dairy farming was primarily responsible for the case study dairy farm's survival. They were able to use it to complete a rapid, mass cattle evacuation before infection could set in. Dairy shed insurance claim settlement and repair was faster than woolshed repair for the same reasons.

After the initial response stage ended, emergency aid was rolled back and public attention diminished. The sudden loss of attention and aid added to the stress of the repair slowdown that marked the transition to short-term repair. The Rural Support Trust did great work maintaining momentum by advocating on behalf of farmers and organising community events. The transition from short-term repair to long-term re-planning decreased outside aid and increased stress again. The on-going recovery process is itself the greatest source of secondary stress.

The insurance process began on the day of the earthquake, but became the primary focus during the short-term repair stage. This process contributed to farmer stress. In December 2016, EQC and private insurers came to a deal where in by private insurers would handle earthquake claims covered by EQC (EQC 2016). This new deal was meant to streamline the claims process, but may not have worked as intended in all cases. A debrief post-claims resolution would have helped to improve the process. Farmers reported that involving lawyers early in the process decreased stress levels.

Long-term re-planning takes years as each farm continues to adjust to their new situation. The case study farms addressed and applied earthquake lessons to prepare for the next earthquake or large-scale disaster. This meant land-use and business plan changes. Depending on previous experience, this took the form of conservatism or exploration of expanding alternate revenue avenues. The key to successful re-planning was taking into account the concepts of cascading hazards and cascading effects. This includes grasping the concept that physical hazards interact. The inevitable breaching of a landslide dam may re-damage previously repaired fences, and winter rains may reactivate landslides to re-damage fences. Secondly, it includes anticipating that the compounding effects of damage, repair, recovery and post-emergency aid isolation will cause stress as time progresses. Also, that the decision to make one recovery step may negate or advance another one. A strong and adaptable farm plan post-earthquake can improve farm resilience moving forward.

New Zealand is an earthquake-prone country with large areas of rural farmland. More research is needed to understand the impact of earthquakes to these areas. This will allow further development of farm-scale specific strategies and recovery processes. The 14th November 2016 earthquake is one of the most complex earthquakes in modern New Zealand history. The second largest earthquake in the same rural region was the 1848 Marlborough earthquake (**M**7.5) (Rattenbury *et al.* 2006). The high probability of another large earthquake impacting rural New Zealand necessitates effective preparation. Section 5.3 lists recommendations for farmers and non-farmers operating the in rural sector to improve earthquake preparedness, response and recovery.

## 5.3 Recommendations

From analysis of the three case studies, several recommendations for farmers and organisations involved in farm earthquake recovery were developed. These are as follows:

<u>For farmers:</u>

1. Hire a lawyer before an earthquake occurs to review current insurance policies and clarify the understanding of policy coverage. Post-earthquake, involve a lawyer early in the insurance claim process.

2. Pre-earthquake, conduct a farm survey to identify hazard zones, vulnerabilities and resources. Make note of on-going conditions like climate change that influence vulnerability. Include seasonal changes.

3. Acquire backup components or systems for all essential services (water, power, telecommunications and transportation).

4. Cultivate human resources both off- and on-farm. Develop off-farm neighbour, community and regional networks.

5. Maintain a post-earthquake recovery and impact timeline.
6. Consider the cascading effects of hazards when making land-use decisions.

<u>For supporting organisations:</u>

1. Recognise and expand mental health resources. Address the stress created by the removal of emergency aid and assistance. Combat the magnified feelings of isolation and stress that occurs when outside aid organisations leave the area.
2. Develop resources for post-earthquake recovery focusing on land-use and business plan changes.
3. Insurance agencies should conduct post-earthquake insurance process debriefs with clients.
4. Consider the impacts of cascading hazards in post-earthquake recovery plans.
5. Recognise and consider the influence of farm type on recovery stage length and timing.

## 5.4 Further work

The analysis of the case studies has captured the impact of the Hurunui/Kaikōura earthquakes and the recovery timeline on three farms. The initial aim of this study was to identify the influencing factors in New Zealand farm earthquake impact and recovery. More studies are required to understand the extent and variety of impacts and recovery timelines for the different farm types in New Zealand. To further advance this goal, the following future research is necessary:

- Further interviews to expand the case study pool beyond three. This may include a questionnaire to >100 Hurunui farmers and the inclusion of more geographically isolated farms.
- Conduct workshops with Hurunui farmers to discuss land-use planning changes as a result of shocks/ stresses (*e.g.,* earthquake, drought, policy).
- Conduct case studies, questionnaires and workshops with farmers in other parts of New Zealand regarding their earthquake impacts and recovery in order to capture topographic, farming type, demographic and regional variations.

- Conduct interviews with local, regional and national farm-focused NGOs to expand on the understanding of the timing and specifics of their contributions.
- Develop of a standardised methodology for capturing the cascading effects of earthquake impacts on farm recovery.
- Develop a framework for analysing farm-scale earthquake impacts and recovery.

This thesis, in combination with future research, will inform improved land-use changes to reduce earthquake impacts, contribute to national understanding of the outside support needed by farms' during earthquake recovery and improve farm earthquake resilience.

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# Appendix A **Historical Rural Earthquake Impact Cases**

The following is a collection of rural earthquake impact cases from previous literature.

On July 21st, 1925, a **M** 7.7 earthquake occurred on the White Wolf fault near Kern county, California; it was followed by several weaker aftershocks (Oakeshott 1955). The agricultural damage following the 1952 Kern County, California earthquake was minimal (Steinbrugge & Moran 1955). Only cropland damage is mentioned in the reports. The farmers improvised, adapted and recovered rapidly. The Kern County Agricultural Department reported a total loss of twenty-three and a half million dollars, but the authors estimated the losses were closer to five to seven million dollars. The annual crop report supports this lower loss estimate as well (Grimm 1952). Most of the almost thirteen million loss compared to the previous year's profits to unfavourable weather and economics. The farm vulnerabilities mirror those of the farms discussed in this study. The electricity system was down for two days (Steinbrugge & Moran 1955). The water systems required repair as various concrete irrigation canals and underground water pipes were cracked. Many fields suffered surface fracturing.

On June 17th, 1929, a **M** 7.8 earthquake occurred near Murchison, South Island New Zealand (Stephens 2016). Landslides and rockfall were made worse by heavy rainfall as farms and roads throughout the Greymouth, Nelson and Westport Districts were damaged and destroyed.

On May 18, 1940, a $\mathbf{M}_w$ 6.9 earthquake occurred on the Imperial Fault near Imperial Valley, California (California Institute of Technology 2013). On October 15th, 1979, a **M** 6.5 earthquake occurred on the same fault (Johnson *et al.* 1982). Farmer knowledge was used to compare the 1940 and 1979 earthquakes. Near Holtsville, California fissures and sand boils caused by the 1979 earthquake occurred in areas that had not been affected by the 1940 earthquake. Bulldozers were used to relevel the slumping ground and fractured tile drain required replacement (Youd & Wieczorek 1982). Several unpaved farm lanes were also destroyed by fissuring. Near Gadsen, Arizona, an area that had experienced liquefaction and irrigation and canal drainage deformation in the 1940 earthquake, experienced no liquefaction after the 1979 earthquake. The 1940 earthquake damaged irrigation canals (Ulrich 1941). According to Ulrich (1941), the damage was too widespread to give specific details; sixty miles of canals were damaged, destroyed or drained.

On September 13, 1986, a series of earthquakes, the strongest was **M** 6.2, occurred near Kalamata, Greece (Anagnostopolous *et al.* 1987). The electrical, water and telecommunications networks were temporarily inoperable. Gazetas *et al.* (1990) reported no liquefaction after a detailed survey; rockfall in mountainous areas and fissuring occurred across the region. Farmers were not directly or severely impacted by the earthquake; the flood of food aid that followed was more devastating (Coburn & Spence 2002). More devastating to the farmers' recovery was the flood of outside food aid into the area. Tourism suffered slightly as well.

On May 21st, 2003, a $\mathbf{M}_W$ 6.8 earthquake occurred near Zemmouri, Algeria; it was the latest in a centuries long line of devastating earthquakes (Bouhadad 2013). The 2003 earthquake triggered a tsunami, just like the 1980 El-Asnam $\mathbf{M}_S$ 7.3 earthquake. Unlike other Algerian earthquakes, Zemmouri's epicentre was in far eastern Algeria (Harbi *et al.* 2007). The quake triggered landslides, rockfall, liquefaction, ground fissuring and damaged electricity, telecommunications, water systems and transport routes (both roads and airports). The area affected in 2003 was highly urbanised. Due to the arid nature of southern Algeria, most of the population is situated in the hilly, seismically active north (Bouhadad 2013). The 1980 El-Asnam earthquake caused most of the structural damage was related to ground shaking, not coseismic hazards (Leeds & Jennings 1983). Tectonic downwarping, uplifting and liquefaction related ground subsidence led to the submerging of many acres of farmland and the creation of a two-square kilometre lake. A major irrigation pipe line was ruptured due to its path across the fault. Roads and railways required rebuilding and temporary rerouting, in the cause of the roads. Ground deformation and liquefaction damaged bridge approaches, created sand boils and sunk trees. Landslides occurred within 10km of the fault. The damage was minor.

On May 12th, 2008, a $\mathbf{M}_S$ 8.0 earthquake occurred near Wenchuan, China (Yu *et al.* 2010). Landslides and flooding were significant coseismic hazards that disrupted transportation by blocking and destroying floods and bridges (Edwards 2009). The earthquake happened in the dry season, just before the rainy season. Heavy rain increased the number of landslides; this continued more than six months later. Some fault surface rupture was reported along rural roads and on farms (Yu *et al.* 2010). Landslides were responsible for more than twenty percent of event related deaths and created many ‘quake lakes’ by blocking river valleys. Channels were carved into some of the landslide dams to trigger a safe breach and lake draining. Liquefaction was more of problem in the plains and around rivers, landsliding was more of a problem in the steep, mountainous areas. Recovery aid was supplied by China (mostly via the military) and internationally. The Food and Agriculture Organisation supplied seeds, production materials and technical training to two rural villages (Edwards 2009).

On April 6th, 2009, a $\mathbf{M}_w$ 6.3 earthquake occurred near L’Aquila, Italy (Kongar *et al.* 2015). Co-seismic hazards include: surface rupture, slope instability, rockfall, underground cavity collapse and liquefaction (ground settlement, sand boils and volcanoes). Rockfalls and landslides, the major cause of road blockages in the rural areas, were worsened by heavy rain in the days after the quake. Rural tourism, part of the agricultural sector, is valued part of L’Aquila’s economy (OECD 2009). Closed roads and nervous tourists limit the growth in this area.

On February 27th, 2010, a $\mathbf{M}_w$ 8.8 earthquake struck in the central southern Chile (EERI 2010). The earthquake and tsunami killed hundreds of people and destroyed thousands of buildings. The wine, grain and fruit industries suffered the most notable non-structural damage. The three regions most affected (O’Higgins, Maule and Bío Bío) also contained about half of Chile’s agriculture (ECLAC 2010). According to ECLAC, although exports were projected to increase across Chile, they would not do so in the three affected regions (ECLAC). The regions account for approximately thirty percent of Chile’s food and beverage exports. The estimated damage costs to agriculture was 300 million US dollars (Núñez 2010). Despite its importance, specifics about the damage to the farms are difficult to find.

On August 24th, 2014, a **M** 6.0 earthquake occurred near Napa Valley, California (Gordon 2015). The earthquake occurred at the end of the dry season and during a multi-year drought. The consequently low water table inhibited landslides and liquefaction. Napa is best known for its wine production (Lapsley & Sumner 2014). Shaking broke bottles and knocked over caskets, but the damage was considered insignificant.

On April 25th, 2015, a **M** 8.1 earthquake occurred in Nepal (Zhao 2015). 8700 people died, hundreds of thousands of buildings were destroyed and landslides, barrier lakes, liquefaction and avalanches were triggered. According to the Nepal ALIA (FAO 2015), a close examination of the 2015 earthquake impact on the agriculture of six districts, seventy-six percent of households are rural and agriculture makes up 35% of the GDP. The earthquake occurred during the harvest of wheat, during the planting of maize and just before the planting of rice. Most of the wheat, important during monsoon season (June-September) had been harvested, but there were massive stored crop and seed losses (40% of household reporting at least 75% loss). Landslides and ground deformation were the largest contributors to standing crop loss. Seeds were mainly stored near houses and were destroyed during shaking induced collapse. Many household lost tools (ploughs, water tanks, livestock sheds, etc.). There appeared to be higher livestock losses due to indirect earthquake affects (e.g. disease), than the geological hazards themselves.

On the 14th and 16th of April 2016, **M** 6.5 and **M** 7.3 earthquakes, respectively, occurred near Kumamoto on Kyushu Island, Japan (Japan Meteorological Agency 2016). The Mainichi newspaper (2016) reported that the total agricultural earthquake damage was over one-hundred billion yen, thirteen-million NZD. The greatest costs were due to damaged storage reservoirs and rice paddies and to surface rupture through fields. The rice paddy damage was so severe that it was thought a whole year's production would be lost. Several thousand livestock, mostly birds, died because of the earthquakes.

# Appendix B **Block Models**

Block models of the three case study farms. Pre-earthquake, immediately post-earthquake, April 2017 (Five months after earthquake), August 2017 (nine months after earthquake and time of first interview) and January 2018 (fourteen months after earthquake and time of second interview). Block models are not to scale. The cartoon representation has been done to preserve confidentiality.

Farm A: Pre-earthquake

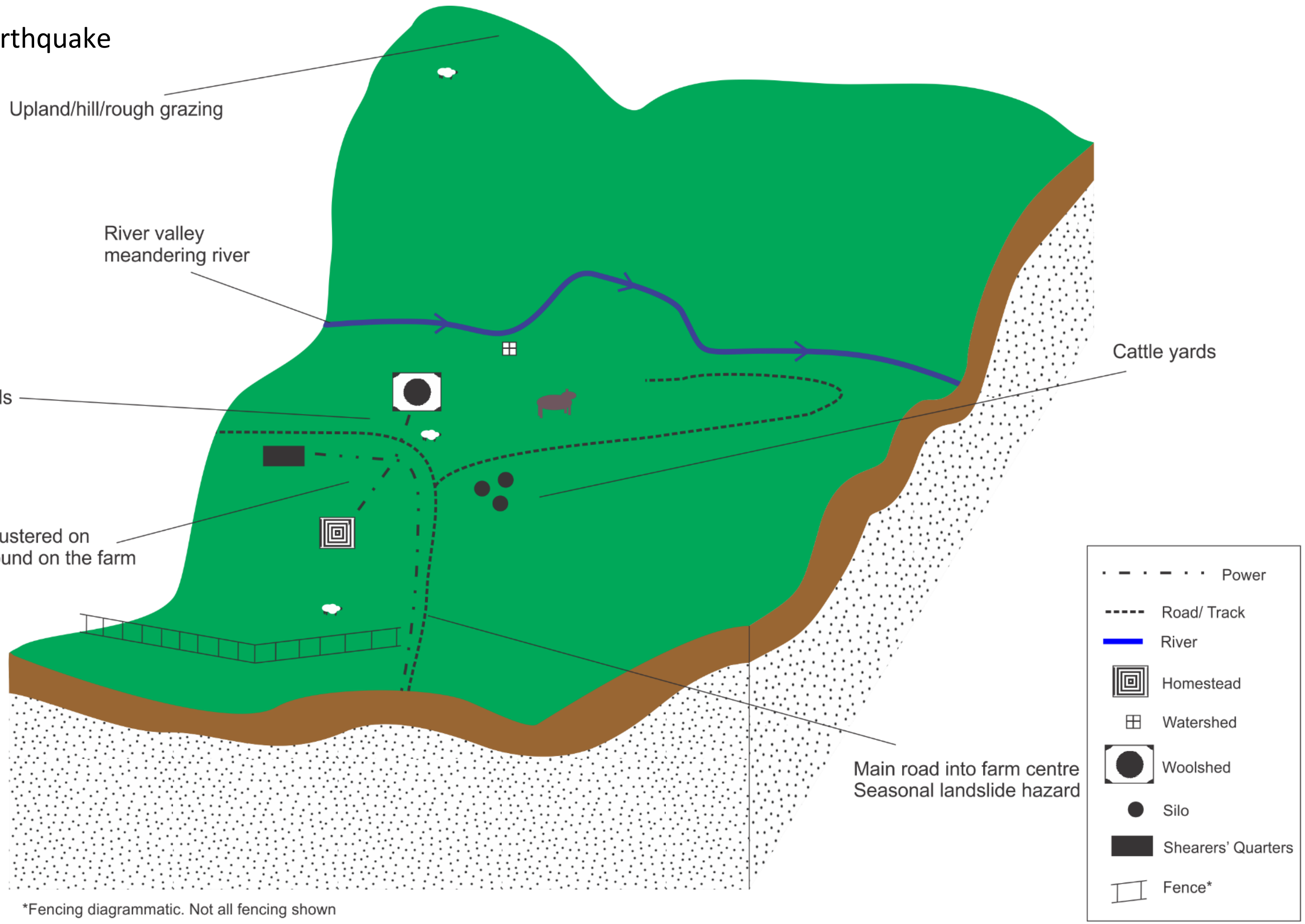


*Figure 20 Pre-earthquake block model of Farm A. Farm A is an extensive mixed sheep and beef farm on hill country. Not to scale. Cartoon representative to confidentiality.*

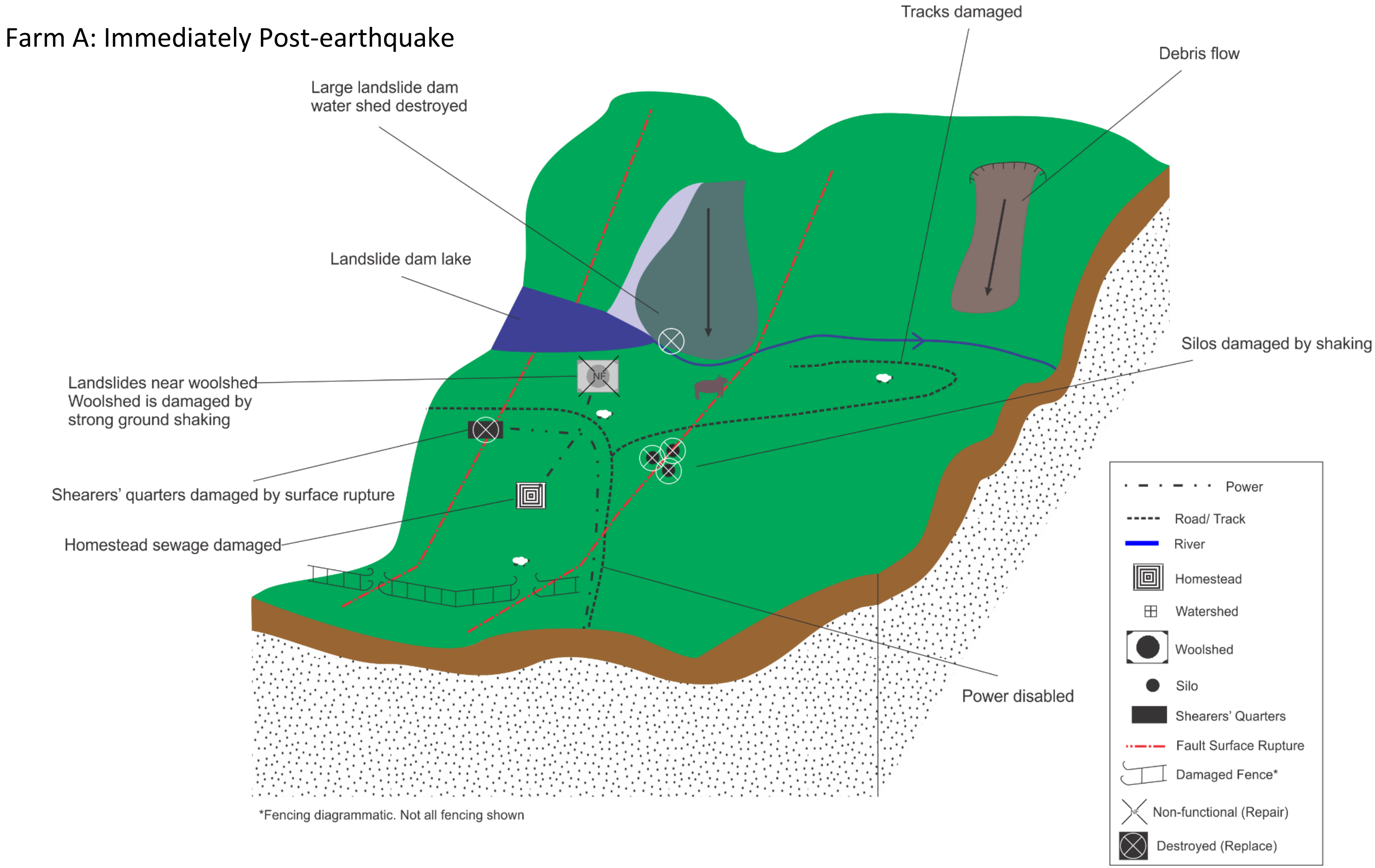


*Figure 21 Immediately post-earthquake block model of Farm A. A large landslide buried the water pump. Surface ruptures, landslides and shaking damaged or pose an imminent risk to other farm infrastructure.. Not to scale. Cartoon representative to confidentiality.*

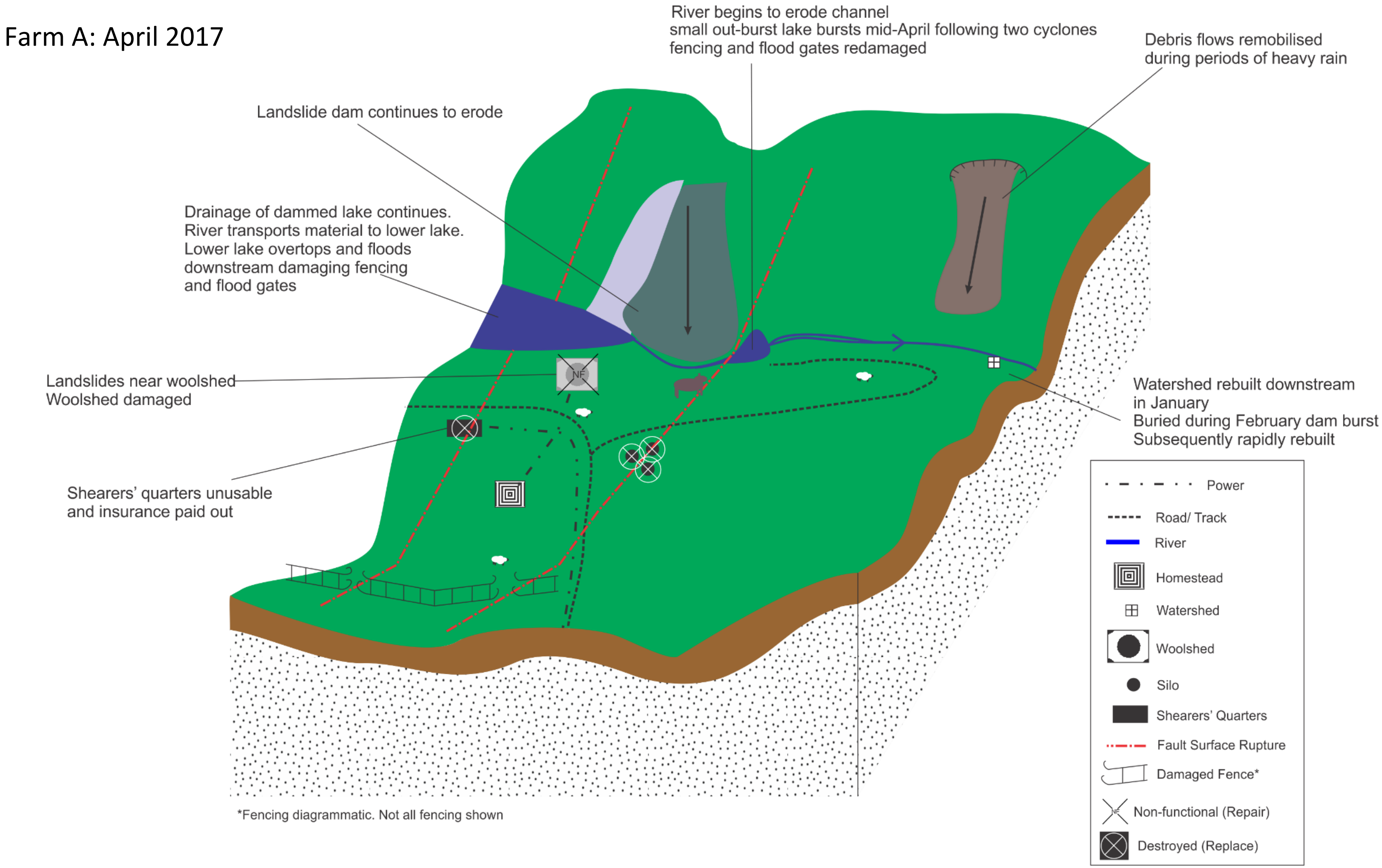


*Figure 22 April 2017 five months post-earthquake block model of Farm A. The landslide dam lake overtopped several times and has re-damaged fences and the replaced water pump. Another smaller lake has formed. April cyclones possibly triggered landsliding and some overtopping. Not to scale. Cartoon representative to confidentiality.*

Farm A: August 2017

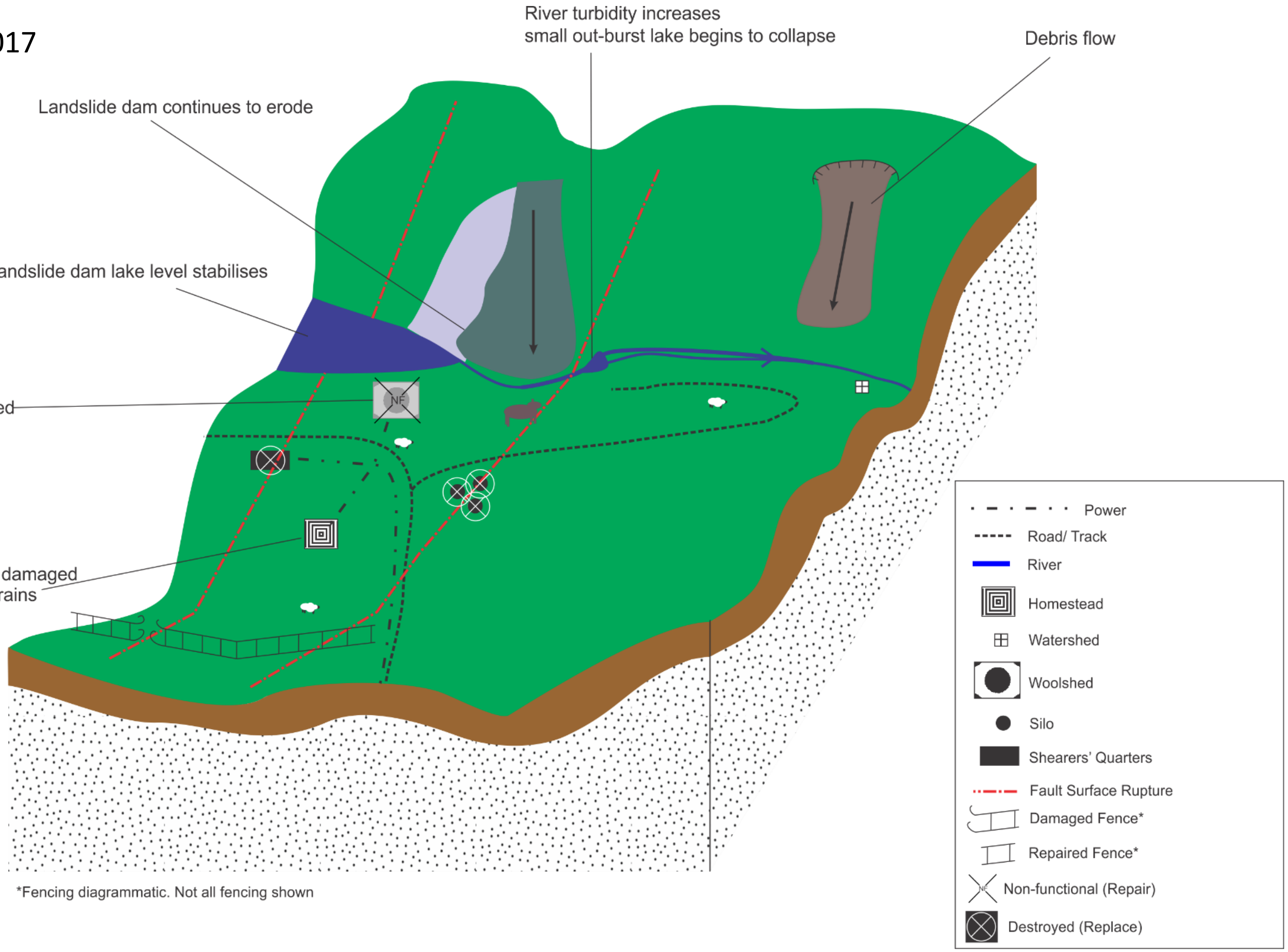


*Figure 23 August 2017 Nine months post-earthquake/time of first interview block model of Farm A. The smaller landslide dam lake has begun to collapse. Some infrastructure has been repaired, others wait for insurance to be settled. Not to scale. Cartoon representative to confidentiality.*

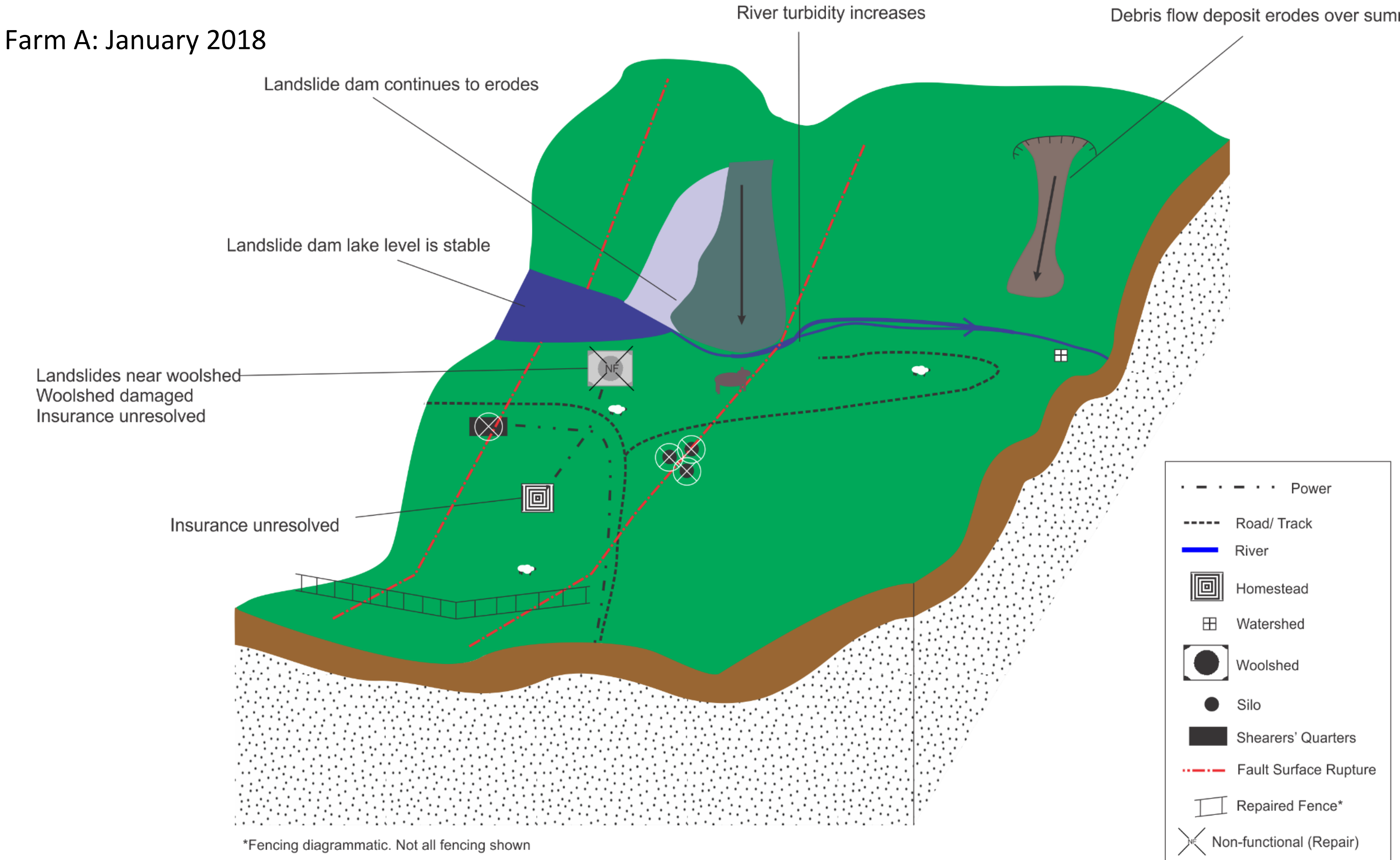


*Figure 24 January 2018 Fourteen months post-earthquake/time of first interview block model of Farm A. Some infrastructure has been repaired, others wait for insurance to be settled. Not to scale. Cartoon representative to confidentiality.*

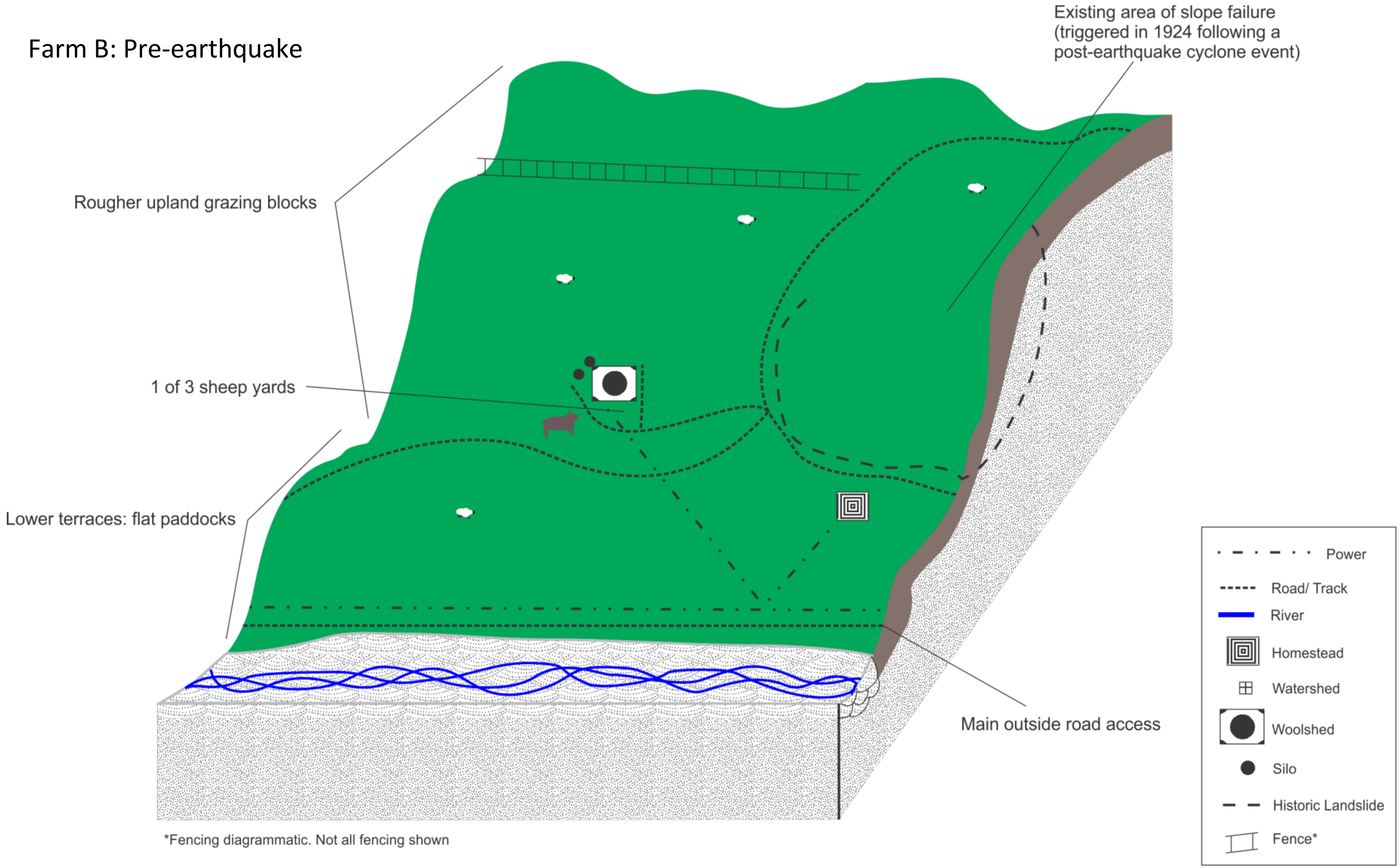


*Figure 25 Pre-earthquake block model of Farm B. Farm B is a medium mixed sheep and beef farm on steep hills with small flats. Not to scale. Cartoon representative to confidentiality.*

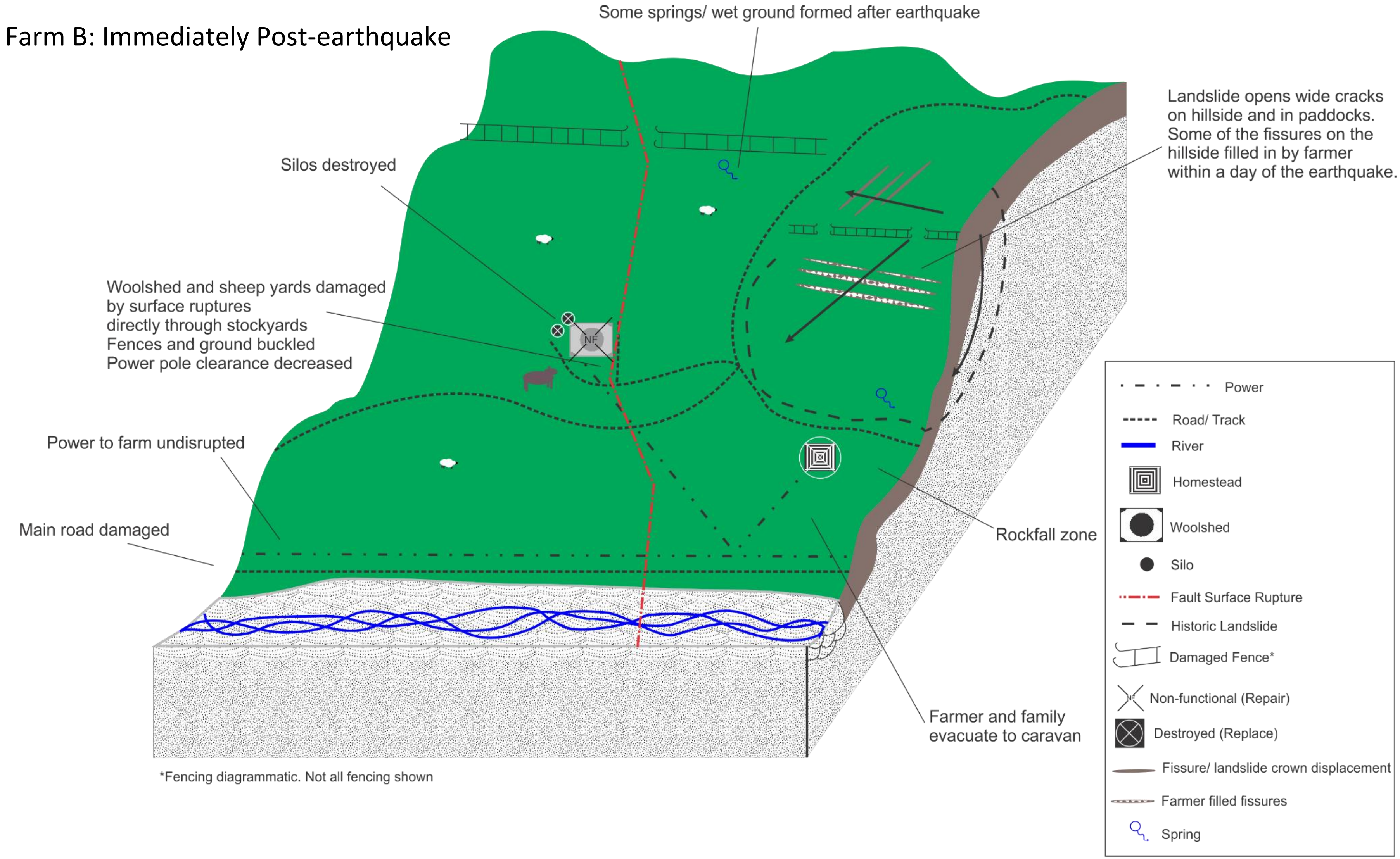


*Figure 26 Immediately post-earthquake block model of Farm B. Large landslide behind the homestead reactivates. Major damaged caused by surface rupture through the woolshed stockyards. Not to scale. Cartoon representative to confidentiality.*

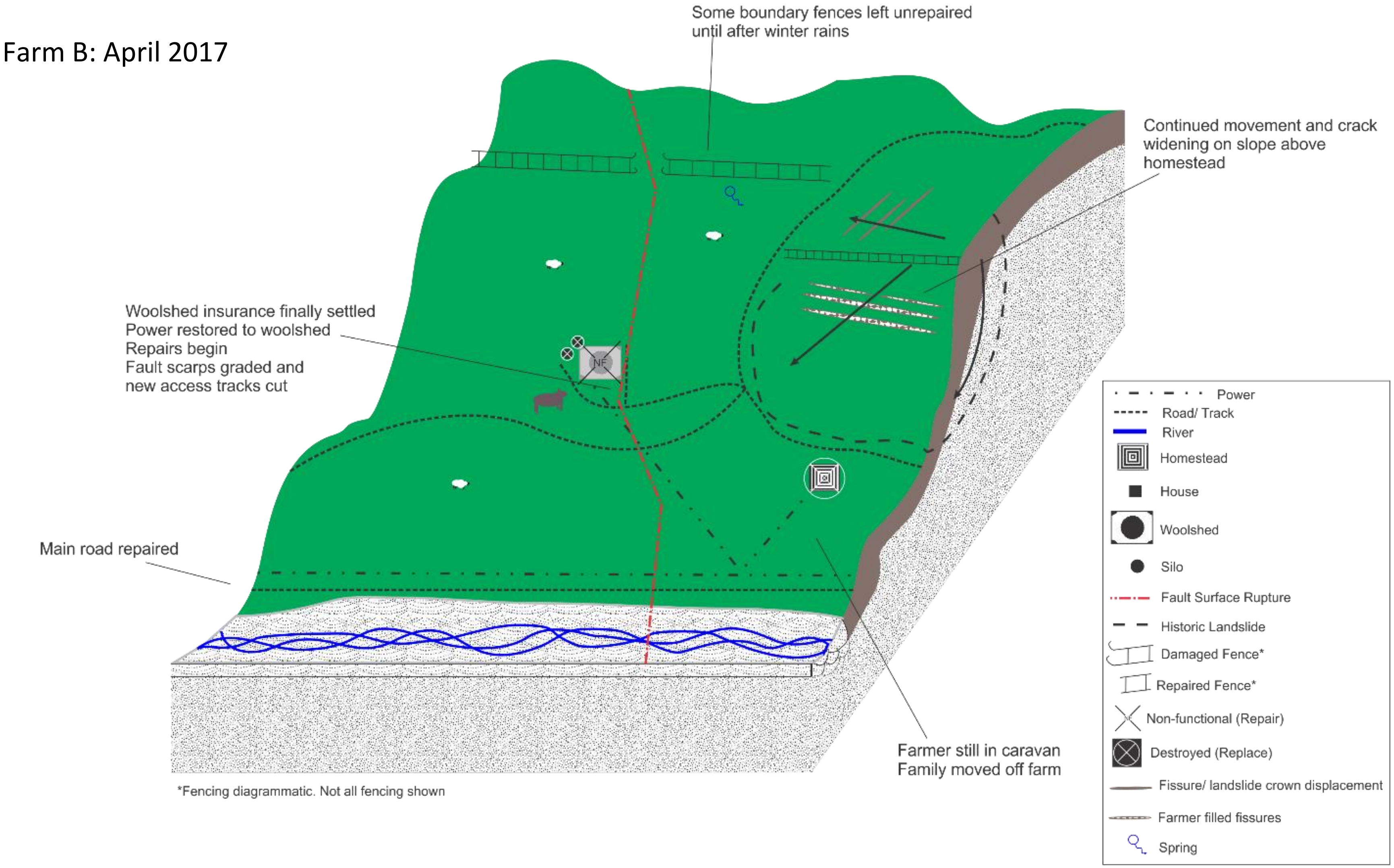


*Figure 27 April 2017 Five months post-earthquake block model of Farm B. The large landslide continues to move. Power restored after woolshed insurance settled, 5 months after earthquake. Homestead insurance claim settlement process on-going. Farmer family living off-farm. Some infrastructure repairs (e.g., fences) delayed to reduce cascading on-going hazard impacts. Not to scale. Cartoon representative to confidentiality.*

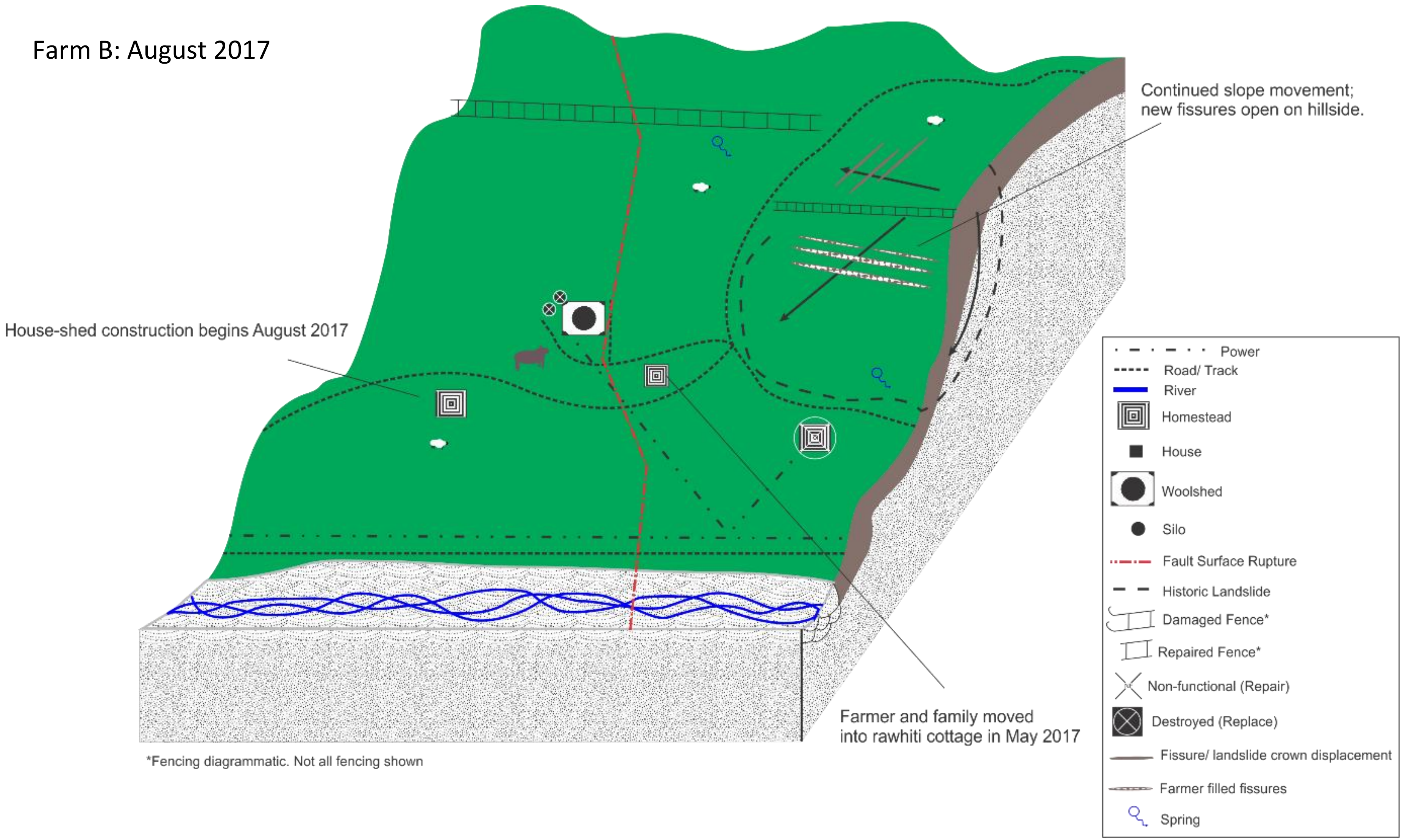


*Figure 28 August 2017 Nine months post-earthquake/time of first interview block model of Farm B. Large landslide continues to move. Rawhiti cottage installed on farm and farm family moved back on. New homestead constructions starts. Not to scale. Cartoon representative to confidentiality.*

Farm B: January 2018

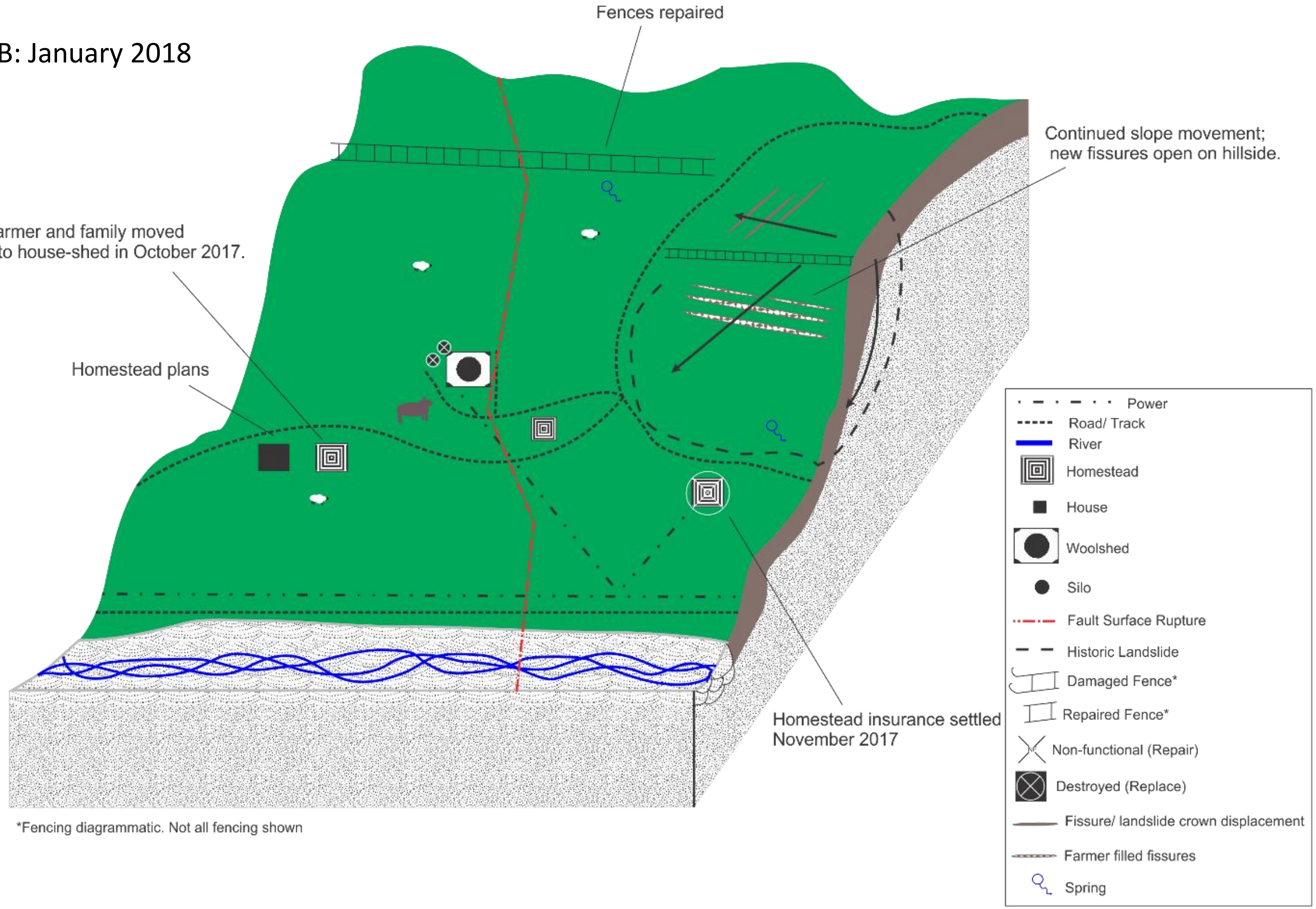


*Figure 29 January 2018 Fourteen months post-earthquake/time of first interview block model of Farm B. Large landslide continues to move. New homestead-shed completed and farmer family moved in. Insurance is settled. Cartoon representative to confidentiality.*

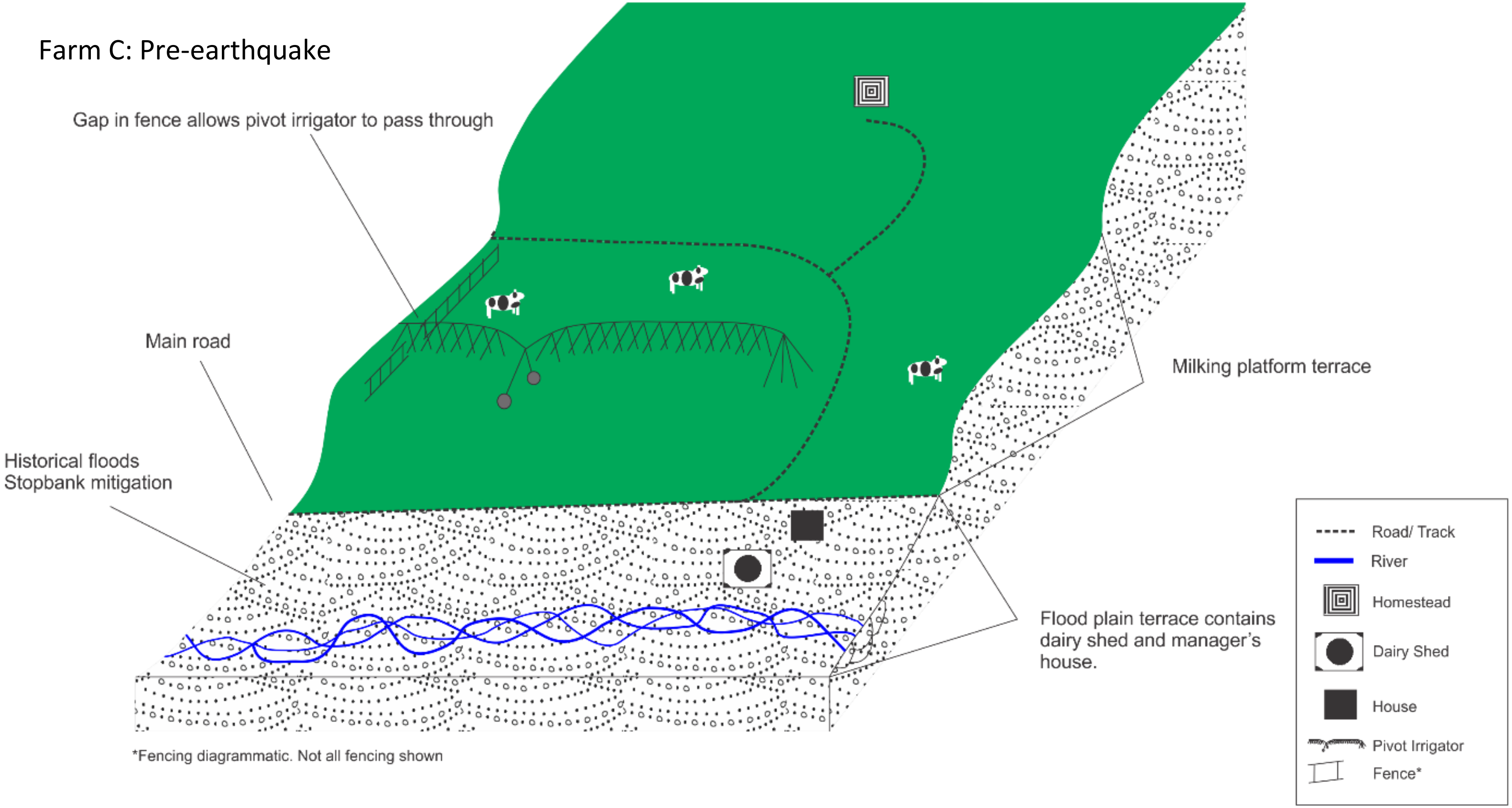


*Figure 30 Pre-earthquake block model of Farm C. Farm C is a dairy farm on low relief, river terraces. Not to scale. Cartoon representative to confidentiality.*

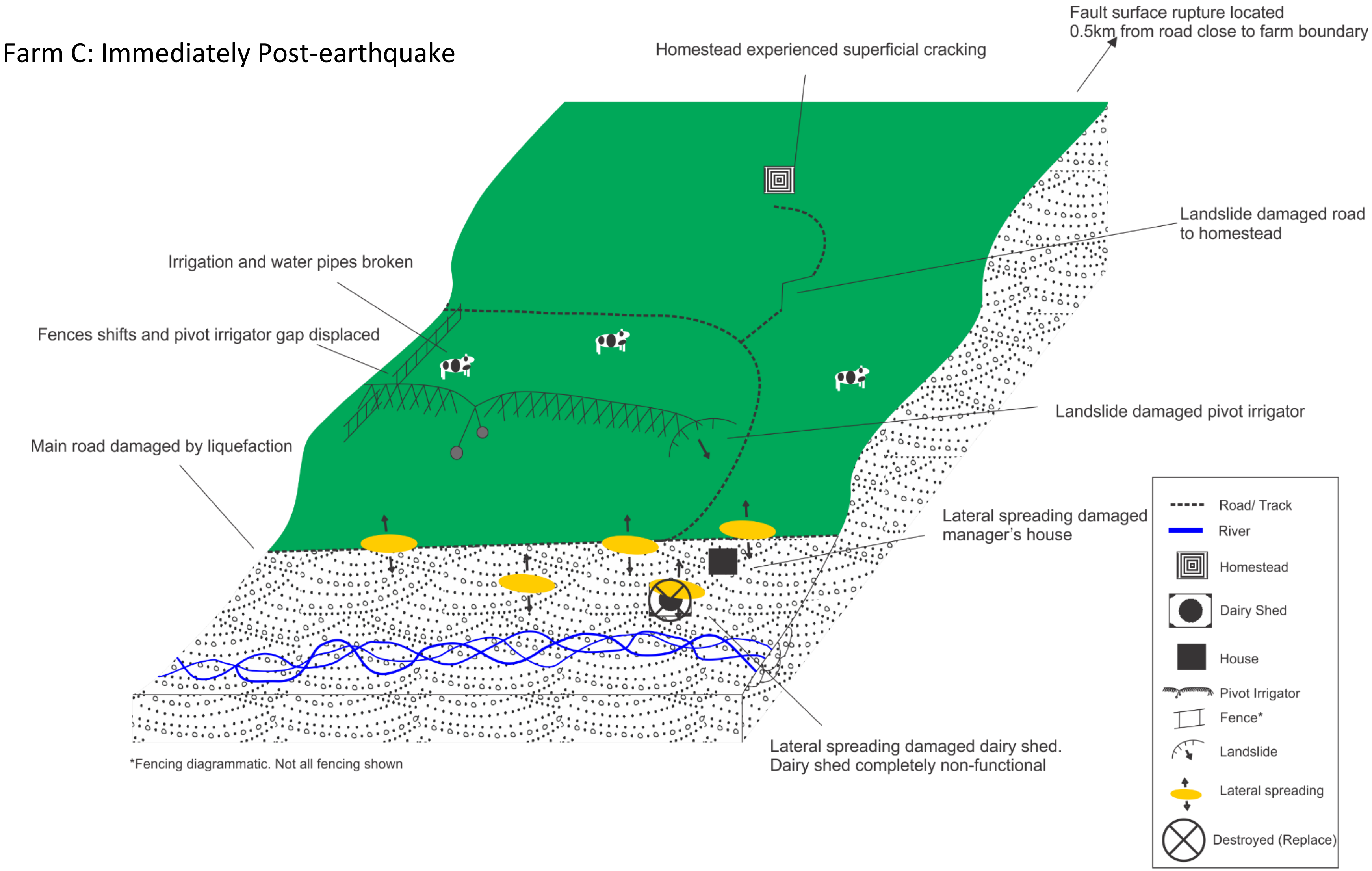


*Figure 31 Immediately post-earthquake block model of Farm C. Liquefaction makes the dairy shed non-functional and the main off-farm road impassable. The damaged to the dairy shed endangered the lives of 1000 dairy cows and prompted a large-scale evacuation. Not to scale. Cartoon representative to confidentiality.*

Farm C: April 2017

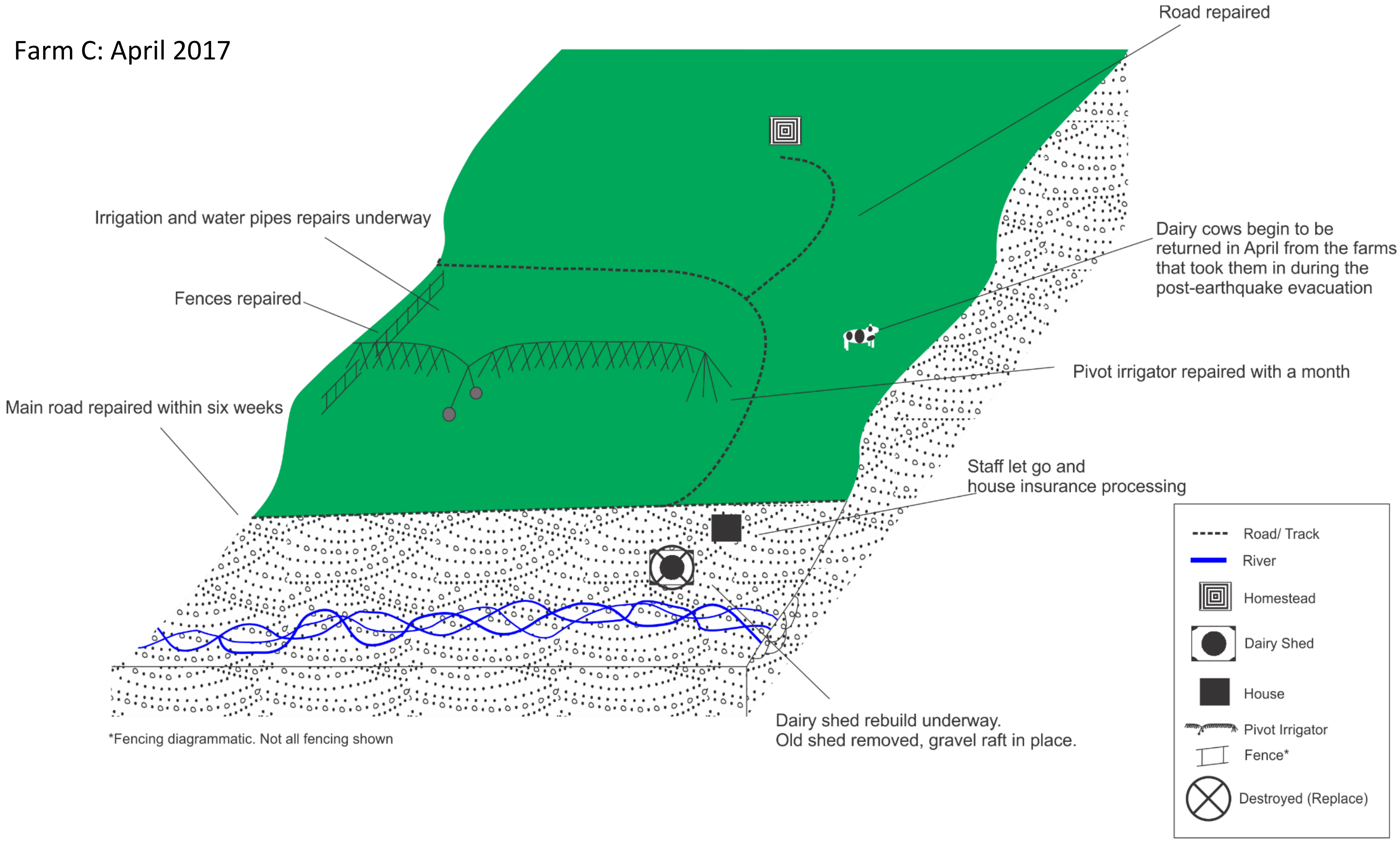


*Figure 32 April 2017 Five months post-earthquake block model of Farm C. Irrigation repairs mostly complete. Dairy cows still off-farm while new dairy shed under construction. Not to scale. Cartoon representative to confidentiality.*

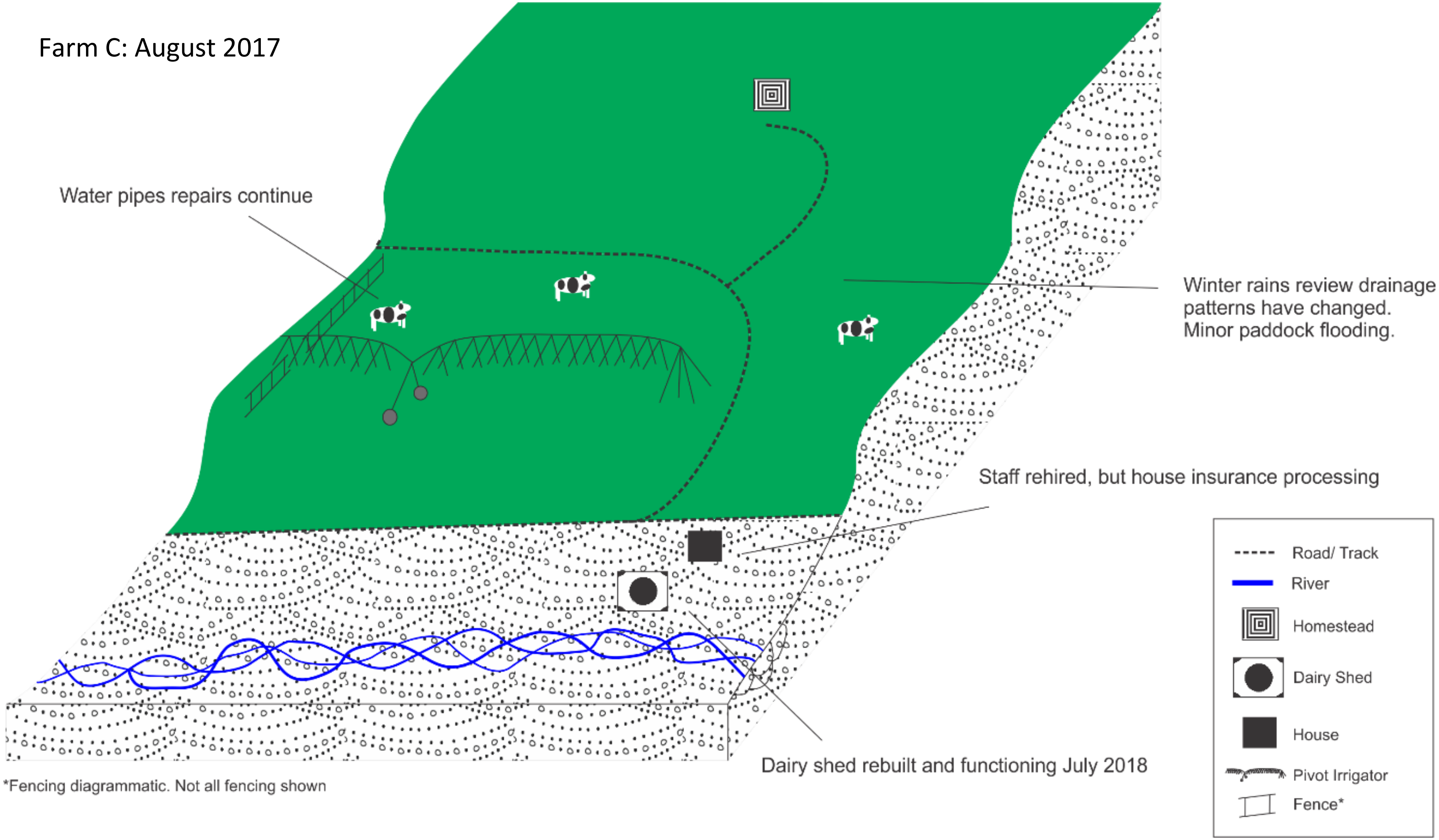


*Figure 33 August 2017 Nine months post-earthquake/time of first interview block model of Farm C. Dairy cows returned and dairy shed running by late July. Staff housing still under repair and insurance settlement process on-going. Some drainage change related flooding. Not to scale. Cartoon representative to confidentiality.*

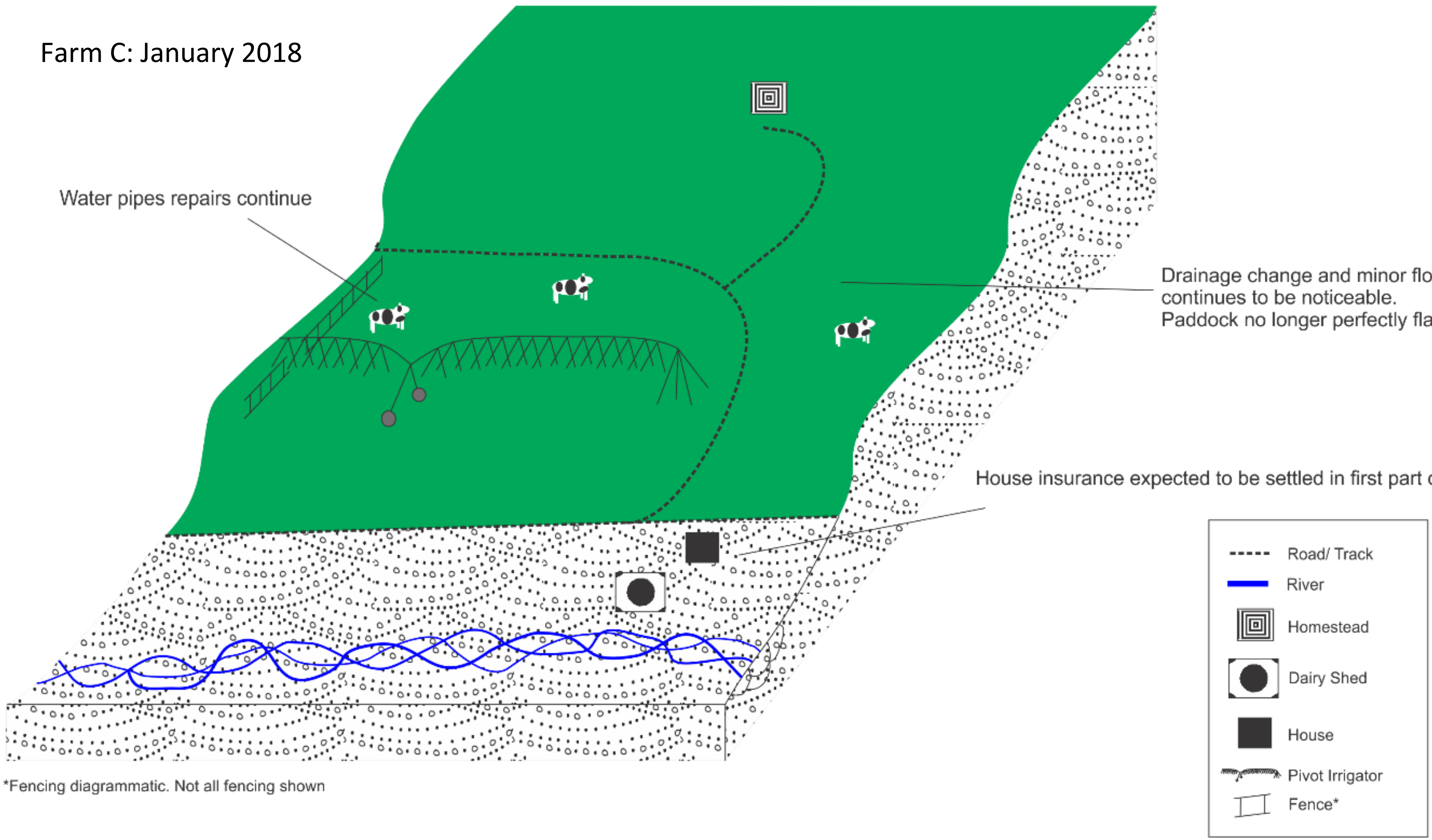


*Figure 34 January 2018 Fourteen months post-earthquake/time of first interview block model of Farm B. On-going minor water pipe and fence damage repairs. Staff housing insurance claims close to settlement. Cartoon representative to confidentiality.*

## Appendix C **University of Canterbury Human Ethics Application**

Appendix C contains all documentation associated with the approved low risk University if Canterbury Human Ethics application.

These documents are as follows:

- Human Ethics Committee application approval
- Participant information and consent sheets
- Round 1 Questions list
- Interview timeline handouts

# Ref: HEC Application 2017/43/LR - McHale

Human Ethics
**Sent:** 31 July 2017 16:40
**To:** Jess McHale
**Cc:** Clark Fenton
**Attachments:** 2017-44 LR - McHale Approv~1.pdf (183 KB)

Dear Jess,

Thank you for your response to the Human Ethics Committee's comments on your recent application.

I am very pleased to advise that the Committee has reviewed your feedback and approved the application; please see the letter attached.

Kind Regards,

Rebecca Robinson
Ethics Coordinator and Erskine Programme Administrator
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Ph: +64 3 369 4588, Ext: 94588
Email: human-ethics@canterbury.ac.nz
Ethics hours of work: Mon 2.30-5pm, Tues 8.30-11am, Wed 8.30-5pm, Thu 2.30-5pm, Fri 8.30-5pm

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# Development of Methodology for Analysing Cascading Hazard Impact on Farm Infrastructure with Hurunui Region Farm test cases following the November 14th, 2016 M 7.8 North Canterbury Earthquake

## Information Sheet for participation in Interview Research

Thank you for agreeing to participate in this study. Please read the information sheet and read and sign the attached consent form.

This information sheet outlines the purpose, benefits and methods of the research. It also explains your rights as a participant in this study. If at any time, you with to enquire about this research, please contact any of the research contributors listed below. This research project is funded by EQC Capability Fund, Resilience to Natures Challenge, Environment Canterbury and the Mason Trust.

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### Project Background

**The purpose of this study:**

- Develop a framework for analysing cascading hazard impact on farm infrastructure model with a focus on post-event impact analysis and future land-use planning

**How this purpose relates to you:**

- This interview and the related exercises aims to gather information about your experience with the November 2016 earthquake and its impact on your farm.

**Benefits of this research:**

- Develop rural/ agriculture specific model for disaster impacts
- Increase understanding of cascading hazards in a rural setting

**Research Methods:**

- This research will consist of one-on-one interviews with farmers in the Hurunui District. Participants were chosen to reflect a cross-section of scale, farm type and impact severity.
- Information gathered from these interviews will be used to identify relationships between hazards, hazard mitigation, disaster recovery and farm operation in order to improve land-use planning and

hazard mitigation in the future.

**Interview Participation:**

If you choose to take part in this study, your involvement in this project will be at least two –approximately two-hour meetings. The meetings will include a semi-structured interview, two timeline exercises and a mapping exercise. There is also anticipated to be informal discussions between you and the researchers during any farm surveying visits. These will, as with the interview, be entirely voluntary and based on your availability and consent.

***Interview***: The researcher will work from a list of questions targeting the key areas of interest. General topics will include farm operation, pre-November 2016 disaster experience, the November 2016 earthquake and land-use planning.

***Map:*** The participatory mapping exercise will be linked to the semi-structured interview. You will be asked to incorporate the map into your answers in order to provide spatial context. All maps will be the most up-to-date and available geological, hazard and topographic maps. You will be asked to mark on the map where critical infrastructure, essential services, hazards and hazard impacts are located.

***Timeline:*** The first timeline exercise will ask you to detail the typical annual farm activities and then to detail the activities of the 2016-2017 agricultural year. The second timeline exercise will ask you to verbally walkthrough the events (hazard impacts and your responses) from September 2016 to present. The researcher will fill a timeline, printed on A0 paper, with post-it notes detailing the impacts and corresponding responses (actions).

The maps and timelines will allow for the collection of spatial and temporal context. The goal for the circular timeline is to establish the impact the earthquake and co-seismic hazards had on the operation of the farm. The goal of the impact/ action timeline exercise is to both aid you in remembering the sequence of events and to start identifying hazard impacts and recovery-action relationships. The mapping exercise will also be used to analyse the spatial connections between hazards and their impacts.

***Permission and review of material***

You will be asked permission for the interviews to be recorded with an audio recording equipment. The researcher will also take notes by hand. At the completion of the interview, you will be invited to review the hand-written notes and a summary will be later emailed to you. We would be grateful if you could review this summary, provide corrections and make any clarifying statements within 30 days of receiving it. If you cannot, please just let us know. You will also be provided with a draft of the thesis before submission. We would be grateful if you could review the draft and make any comments or ask any questions within 30 days of receiving it. Again, if you cannot, please just let us know.

In the performance of the tasks and application of the procedures there are risks of reactivating trauma/ stress related to retelling the events of the November 2016 earthquake. You can ask for the interview to be stopped or to take a break whenever you feel the need.

Participation is voluntary and you have the right to withdraw from the interview or decline to answer a question at any time. You may ask for your raw data to be returned to you or destroyed at any point. If you withdraw, I will, remove all information relating to you. However, once analysis of the interviews commences, it will become increasingly difficult to remove the influence of your data on the results.

**Data Storage:**

All recorded notes (notebook, audio recordings and electronic files) will be kept securely in locked room or vehicle (while traveling). Electronic data will be in a password protected folder on the UC servers and a portable hard drive, which will be kept in a locked office. Data on the laptop will be deleted after transfer. At the completion of the project all the data (both written and electronic file) will be handed over to a

*[Jess McHale]*

supervisor for secure keeping for a period of 5 years, after which it will be destroyed. Access to the data will be limited to Jess McHale, Clark Fenton, Thomas Wilson and Sarah Beaven (Geological Sciences, University of Canterbury).

The results of the project may be published, but you may be assured that ever effort will be made to maintain the confidentiality of data gathered in this investigation: your identity will not be made public. No farm will be referred to by its name. They will instead be referred to by their size and farm type (e.g. small mixed sheep-arable farm). Wherever appropriate, you will be referred to by your occupation and a letter (e.g. Farmer A, Farmer B, etc.). Given the small area in which the participants are being selected and the size of the farms, it is improbable that the identities of the participants will be kept completely confidential.

**Data Use:**

The project is being carried out as a requirement for a Master of Science in Engineering Geology by Jess McHale under the supervision of Clark Fenton, Thomas Wilson and Sarah Beaven, who can be contacted at (clark.fenton@canterbury.ac.nz, thomas.wilson@canterbury.ac.nz and sarah.beaven@canterbury.ac.nz). A thesis is a public document and will be available through the UC Library. The information collected may also be published in a peer-reviewed academic journal.

Documents published throughout the study or at the conclusion of the study will be accessible to the participant. If you would like a copy of the thesis – please let me know and I'll send you one.

If you have any questions or concerns regarding this study, please don't hesitate to ask.

This project has been reviewed and approved by the University of Canterbury Human Ethics Committee, and participants should address any complaints to The Chair, Human Ethics Committee, University of Canterbury, Private Bag 4800, Christchurch (human-ethics@canterbury.ac.nz).

If you agree to participate in the study, you are asked to complete the consent form and return the signed form via email (to jess.mchale@pg.canterbury.ac.nz) or in hard copy before at the time of the interview.

Thank you for participating in this study.

*[Jess McHale]*

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+64 3 364 2987

UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

# Development of Methodology for Analysing Cascading Hazard Impact on Farm Infrastructure with Hurunui Region Farm test cases following the November 14th, 2016 M 7.8 North Canterbury Earthquake

## Consent Form for participants in Interview Research

## Contacts

### Researcher

Jess McHale
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### Supervisors

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☐ Participation will involve at least two one-on-one interviews and potentially several follow-up informal discussions with Jess McHale (MSc Candidate) from the University of Canterbury. I understand the interviews will be recorded using audio equipment and written notes. An interview summary will be produced after the interview. I have been given a full explanation of this project and have had the opportunity to ask questions.

☐ I understand that participation is voluntary and I may withdraw from the interview or decline to answer a question at any time without penalty. Withdrawal of participation will also include the withdrawal of any information I have provided should this remain practically achievable.

☐ I acknowledge that this research project is funded by EQC Capability Fund, Resilience to Natures Challenge, Environment Canterbury and the Mason Trust.

☐ I understand that to protect my privacy, any information or opinions I provide during the interviews or through email correspondence will be kept confidential to the researcher, Clark Fenton and Thomas Wilson. I also understand that every effort will be made to maintain the confidentiality of the participants. I understand that the information collected will be used in Jess McHale's Master of Science thesis, which is a public document and will be available through the UC Library, and possibly published in a peer-reviewed academic journal.

☐ I understand that electronic data collected from my interview will be kept on a password protected external hard drive. The external hard drive and written notes will be stored in a locked drawer in a locked office. Access to the data will be limited to Jess McHale, Clark Fenton, Thomas Wilson and Sarah Beaven (Geological Sciences, University of Canterbury). The data will be destroyed after five years.

☐ I understand the risks associated with taking part and how they will be managed.

☐ I understand that I will be sent a summary of the interview after the interview. I understand I will have 30 days to review this summary, provide corrections and make any clarifying statements before the information is used in research.

- ☐ I understand that I will be sent a draft of the thesis before final submission. I understand I will have 30 days to review this draft, make comments and ask any questions before the thesis is submitted.

- ☐ I acknowledge that this proposal has been reviewed and approved by the Department of Geological Science, University of Canterbury and the University of Canterbury Human Ethics Committee.

- ☐ I understand that I can contact the researcher Jess McHale (jess.mchale@pg.canterbury.ac.nz nz) or supervisors Clark Fenton (clark.fenton@canterbury.ac.nz), Thomas Wilson (thomas.wilson@canterbury.ac.nz) or Sarah Beaven (sarah.beaven@canterbury.ac.nz) for further information. If I have any complaints, I can contact the Chair of the University of Canterbury Human Ethics Committee, Private Bag 4800, Christchurch (human-ethics@canterbury.ac.nz)

- ☐ A copy of this consent form and the information sheet have been given to me.

- ☐ I have read, understood and agreed with both the information form and consent form provided to me. All my questions regarding the study have been answered satisfactorily.

- ☐ By signing below, I agree to participate in this research project.

Name:______________________________Signed:____________________________Date:________________

Email address *(for report of findings, if applicable)*:_______________________________________________

*Please return a signed copy of this form via email (to* jess.mchale@pg.canterbury.ac.nz*) or in hard copy before at the time of the interview.*

# Round 1 Questions

1. **Characterise the farm: Could you please describe your farming operation?**
    a. **How large is your farm?**

    b. **What type of farming do you undertake?**

    c. **How many livestock?**

    d. **Do you have irrigation? If so, could you please describe where it is and what times of year it is used.**

    e. **Could you please summarise the different farm activities which occur throughout the year? Which periods are the most important (vulnerable)?**

        i. **What was happening at the time of the November 2016 earthquake?**

    f. **What are the essential services you rely on, such as electricity, transportation access, water, etc.? Could you please rank them in order of importance?**

    g. **What are the essential infrastructure on the farm, e.g. dairy shed, woolshed, etc.? Could you please rank them in order of importance?**

2. **First, can you describe your experiences with hazards/ disasters (drought, earthquakes, landslides, flooding, storms) prior to the November 2016 earthquake?**
    a. **What and when were the hazards/ disasters?**

    b. **How did they impact the farm?**

    c. **What did you do in response to these events (mitigation, land-use changes, different crop/ livestock)?**
        i. **What part (if any) did insurance or outside organisations play in the recovery process?**

3. **So, now we are going to talk about the impacts of the November 2016 earthquake.**
    a. **Can you talk me through what happened and what you did starting in October of 2016?**
        i. **Can we place these in context on this timeline?**

    b. **How were farm assets and essential services impacted (both physically and functionally- broken fences, changed water flow) by the initial earthquake and co-seismic hazards (fault rupture, landslide, liquefaction, etc.)?**

i. **In what order (if known) did the damage occur?**

c. **How were the farm assets and essential services repaired? How long did it take? What does repair mean to you (return to pre-event or improve)?**

d. **Is there anything you have been unable to repair or replace?**

e. **How did you decide which assets and services needed to be addressed first? (interdependency, time of year) Are some assets and services dependent on others? How?**

f. **What long term damage/ disruption do you anticipate?**

g. **Are the farm assets and essential services continuing to be impacted by aftershocks and coseismic hazards (fault rupture, landslide, liquefaction, etc.)?**
    i. **What is the timing of these impacts?**

h. **What steps, if any, have you taken to prevent further damage/ disruption to these assets and services?**

i. **How long did it take to repair these assets and services? Are you still trying to repair or relocate them? How does this continuing damage/ disruption affect other parts of the farm?**

j. **Are the assets continuing to be impacted by hazards (flood, drought, storm events, animals, etc.) that may not be related to the earthquakes? If so, how?**
    i. **How were the farm assets and essential services repaired? How long did it take?**
    ii. **What steps, if any, have you taken to prevent further damage/ disruption to these assets and services?**

k. **What disaster mitigation steps were taken before and after the earthquake? How effective were they?**
    i. **What types of redundancy in assets or services do you have? (e.g. generators, spare equipment, fallow fields, etc.)**

l. **What hazards (landsliding, flooding, droughts, etc.) do you anticipate in the future?**
    i. **What steps, if any, have you taken to address them?**

m. **How has insurance impacted the recovery process**
    i. **Are there problems with what is and is not covered?**
    ii. **When did insurance kick in? Can you tell me what the process was like?**

**n. How have outside organisations (government and farmers' organisations) impacted the recovery process?**
   **i. When did they (or you) first make contact?**
   **ii. What have they done to assist?**
   **iii. What do you wish they did (or did not do) to assist?**

**4. And now let's talk about land-use planning (pre- and post-November 2016 earthquake)**

**a. What was the land-use of various areas on the farm before November 2016? (e.g. where was grazing, fallow fields, native bush, etc.)**

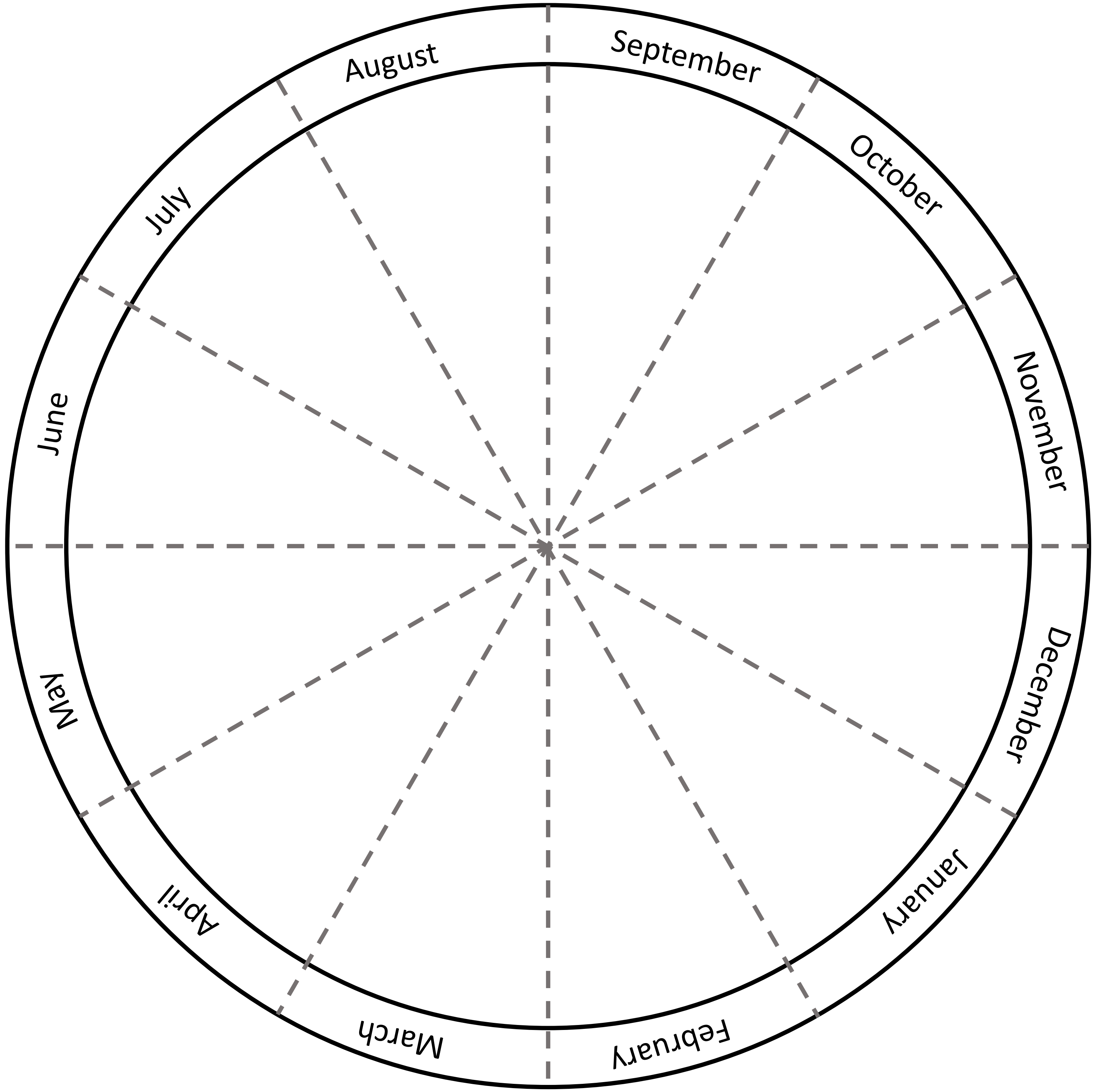
**b. What was the land-use plan in October 2016? Any major projects?**

**c. What (if any) change has been made or needed to be made to the plans post-November 2016?**
   **i. How did the earthquakes and coseismic hazards impact that plan?**

**d. Knowing what you know now about the earthquake, coseismic hazards and their impacts, would you have done something differently? If so, what?**

**e. What short term economic impacts have you felt?**

**f. What long term economic impacts do you expect?**



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